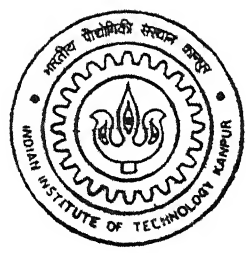


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**DESIGN AND IMPLEMENTATION OF IrDA COMPATABLE
POINT TO POINT OPTICAL WIRELESS LINK FOR INDOOR
APPLICATIONS**

**by
A. Swarna Bai**

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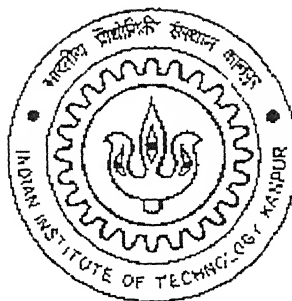
**DEPARTMENT OF ELECTRICAL ENGINEERING
Indian Institute of Technology, Kanpur
May, 2001**

DESIGN AND IMPLEMENTATION OF IrDA COMPATIBLE POINT TO POINT OPTICAL WIRELESS LINK FOR INDOOR APPLICATIONS

A Thesis Submitted
in Partial Fulfillment of the Requirements
for the degree of
Master of Technology

By

A. Swarna Bai



to the

**DEPARTMENT OF ELECTRICAL ENGINEERING
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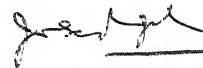
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CERTIFICATE

This is to certify that the thesis work entitled "**DESIGN AND IMPLEMENTATION OF IrDA COMPATIBLE POINT TO POINT OPTICAL WIRELESS LINK FOR INDOOR APPLICATIONS**" by Ms A Swarna Bai, Roll No. 9910404 has been carried under my supervision and the same has not been submitted elsewhere for a degree.

9 May 2001



Dr. Joseph John
Associate Professor
Department of Electrical Engineering
I.I.T Kanpur - 208016

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ABSTRACT

In recent years Wireless Infrared (IR) communication systems are being used widely to provide portable data communication at lower cost. IrDA standards have emerged in order to meet the growing demand in this field. In this thesis an attempt has been made to design an IrDA compatible Indoor point-to-point experimental link with IR LED as a source and PIN photodiode as a detector. IrDA compatible encoder and decoder were designed and implemented in order to reduce the current requirements for driving the IR LED for various data rates. The IR link was tested with a PRBS generator for evaluating the system performance. Current-Intensity characteristic of the LED Source was measured. Sensitivity, Dynamic range and maximum data rate capability of the PIN photodiode based transimpedance amplifier were measured.

The experimental link along with encoder and decoder was tested and the maximum range achieved was 30 cm at a data rate of 115.6 kb/s (1.2 Mb/s after encoding) with single IR LED as the source. The experimental link without encoder and decoder was interfaced to the RS-232 port of the PC and files were transferred from PC to PC for baud rates from 9.6 Kb/s to 57.6 Kb/s upto a distance of 10cm.

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INTRODUCTION

Growth of data communication has been enormous in the last few years. Present systems use wired physical connections, which introduce difficulties in construction and rewiring during the initial system set up and later during expansion phases. An alternative that achieves the same goal for data communication while offering mobility is the wireless network. Traditionally, radio frequency transmission was used in wireless applications. However, the RF spectrum is so congested that it is very difficult to accommodate new high-bit rate applications.

Optical systems with low implementation complexity and no spectrum license requirements provide a possible solution. The use of an optical wireless network for indoor applications offers numerous advantages over the equivalent RF wireless network. The optical infrared energy can typically be contained within the room or communication environment, thus virtually eliminating the problems of interference generated by neighboring users while offering a degree of security at the physical level. The same transmission equipment and optical wavelength can be reused in other parts of the building, thus offering spatial diversity. Moreover, optical wireless systems offer immunity from signal fading. As such, indoor infrared communication has recently gained importance, especially in view of the increased data and mobility requirements of users for both computing and communications.

Serious work on optical wireless systems started in 1993. At present it is a very rapidly developing research area and there is huge interest and commitment in this area by the major communication industries due to its enormous commercial applications.

1.1 BASIC OPTICAL WIRELESS SYSTEM

The basic sub systems of an optical wireless system are Transmitter (LED's or Laser diodes), the medium (the open space between transmitter and receiver), hence the name wireless, and Receiver (PIN or APD based). The link length may be anywhere from a few meters to a few Km. The block diagram of a typical optical wireless communication link is shown in Fig.1.1

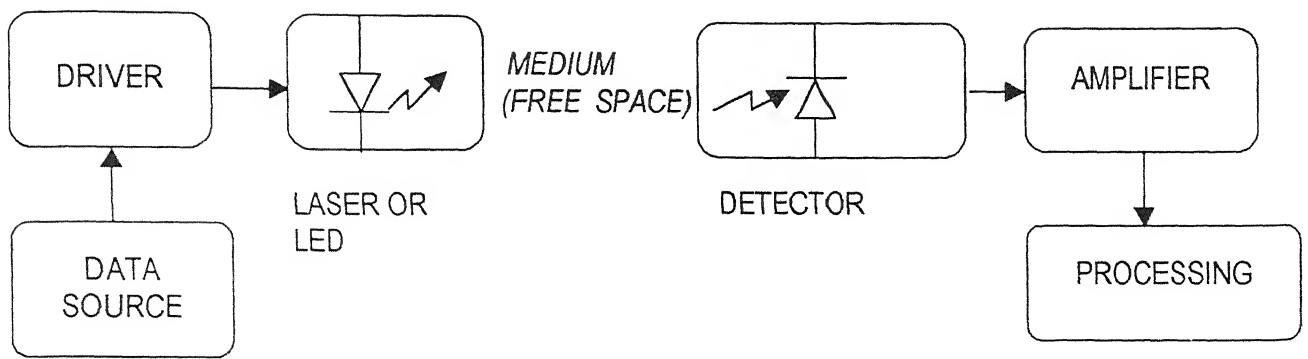


Fig.1.1: Block Diagram of an Optical Wireless Communication Link

A source producing an electrical information signal is to be transmitted to some destination. This source output modulates an optical carrier. The modulated optical carrier is then propagated as a light field through a medium (freespace). At the receiver the field is optically collected and detected to produce an electrical signal, which is further processed by the electronic stages to receive the original information with an acceptable error.

1.2 CHARACTERISTICS OF THE BASIC SUBSYSTEMS AND ASSOCIATED DESIGN CHALLENGES

The characteristics of the optical transmitter, detectors and the free space medium, which form the basic sub-systems of optical wireless communication and the constraints faced while designing are discussed as below.

1.2.1 TRANSMITTER

There are two basic light sources, the laser diode (LD) and the light emitting diode (LED). The availability of high power and broader bandwidth Laser diodes (LDs) at low costs is attractive, especially for outdoor applications. However, for indoor applications LD's pose potential safety hazards, as they are point source emitters. LEDs[1] are large-area emitters and thus can be operated safely at relatively high powers. LEDs are less expensive and harder to damage than LDs. Typical packaged LEDs emit light into semiangles (at half power) ranging from about 10°-30°, making them suitable for directed transmitters. Hence they are the preferred emitters (directed transmitters) for most indoor applications. Non-directed transmitters also frequently employ LEDs oriented in different directions.

LEDs utilize relatively simple drive circuits (without the need for feedback to control output power), are immune from coherency related problems (pulsations, kinks, and modal noise), and operate over a wide temperature range with unparalleled reliability. To compensate for the lower powers, arrays of them can be used. However, LEDs cannot be used beyond 10 Mb/s typically, since LEDs have large rise and fall times, hence not compatible with the short pulses required for high data rates. LDs can be used up to at least 1Gb/s. The wavelength band between about 780 and 950 nm is presently the best choice for most applications of infrared wireless links, due to the availability of low cost LEDs and LDs, and because it coincides with the peak responsivity of inexpensive, low capacitance silicon photodiodes. Table 1.1 presents a comparison between LEDs and LDs [2]

When compared to LDs, LEDs can offer the advantages of higher reliability [3], reduced temperature sensitivity, less complicated drive circuit requirements, immunity to optical feedback, and lower cost due to high yields and simpler packaging technology.

In practical systems, the total amount of transmitted optical power and number of emitting devices is limited by cost, size and power consumption considerations and also by the maximum safety levels that are allowed by IEC standards.

Table 1.1 Comparison between LEDs and LDs

Characteristics	Light-Emitting Diodes	Laser diodes
Spectral Width	25 to 100 nm (10 to 50 THz)	$<10^{-5}$ to 5 nm ($f < 1$ MHz to 2 THz)
Modulation Bandwidth	Tens of kHz to tens of MHz	Tens of MHz to tens of GHz
E/O Conversion Efficiency	10 to 20 %	30 to 70 %
Eye safety	Generally considered Eye-safe	Must be rendered eye-safe. Especially for $\lambda < 1400$ nm
Cost	Low	Moderate to high

1.2.1.1 EYE SAFETY

Optical wireless systems can pose a hazard due to the large optical power of LDs. International Electrotechnical Commission (IEC) sets these eye safety standards [4], and they classify LDs based on their total emitted power, into Class 1, 2, 3A and 3B as summarized in Table

1.2 To achieve eye safety with an LD requires that one pass the laser output through a transmissive diffuser, such as a thin plate of translucent plastic, that destroys the spatial coherence and spreads the radiation over a sufficiently extended emission aperture and emission angle. While such diffusers can achieve efficiencies of about 70%, they typically yield a Lambertian radiation pattern [12], offering the designer little freedom to tailor the source radiation pattern. Computer generated holograms [6,7,8] offer a means to generate custom tailored radiation patterns with efficiencies approaching 100%, but must be fabricated with care to ensure that any residual image of the LD emission aperture is tolerably weak

It is desirable for infrared transmitters to conform to the IEC Class 1 allowable exposure limit (AEL) At pulse repetition rates higher than about 24 kHz, compliance with this AEL can be calculated on the basis of average emitted optical power alone. The AEL depends on the viewing time, wavelength diameter, and emission-semiangle of the source. At 875 nm, an IrDA (Infrared Data Association)-complaint source having an emission semiangle of 15° and diameter of 1mm can emit an average power up to 28 mW. At the same wavelength, a Lambertian source (60° semiangle) having a diameter of 1mm can emit up to 280 mW; at larger diameters, the allowable power increases as the square of the diameter

Table 1.2 Laser Safety Classifications for a Point-source Emitter

Classification	650 nm (visible)	880 nm (infrared)	1310 nm (infrared)	1550 nm (infrared)
Class 1	Up to 0.2 mw	Up to 0.5 mw	Up to 8.8 mw	Up to 10 mw
Class 2 *	0.2 –1 mw	N/A	N/A	N/A
Class 3A	1-5 mw	0.5 –2.5 mw	8.8 –45 mw	10 – 50 mw
Class 3B	5-500 mw	2.5 – 500 mw	45-500 mw	50 –500 mw

* Class 2 applies only to visible light sources

Outdoor point-to-point systems generally use high-power lasers (Class 3B) to achieve a good power budget. Safety standards require these systems to be located where the beam cannot be interrupted or viewed inadvertently by a person. Rooftop or high wall locations are common for these systems [9].

Indoor systems are a challenge because the eye safety standard requires these to be Class 1 eye safe under all conditions. Hence LDs, if used, must have powers less than 0.5 mW, which will not meet the power budget requirements. However, LEDs with much higher launch powers can be used and still remain Class 1 eye safe. This is because of the fact that LED's are large-area-emitters and hence the power is diffused. Arrays of LEDs with substantial launch powers are often employed-which are cost effective compared to LDs for indoor systems [10-13].

1.2.2 FREE SPACE MEDIUM

The link power budget for a point to point free space link are strongly determined by the **atmospheric loss** along the propagation path, which comprises of free space loss, clear air absorption, scattering, refraction, and scintillation. All forms of optical wireless systems experience freespace loss. However, the other sources of atmospheric loss, viz. clear air absorption, scattering, refraction, and scintillation, are only applicable to long distance systems.

Freespace loss defines the proportion of optical power arriving at the receiver that is usefully captured within the receiver's aperture. A typical figure for a point-to-point system with a slightly diverging beam is about 20 dB. For an indoor system with a wide-angle beam it could be 40 dB.

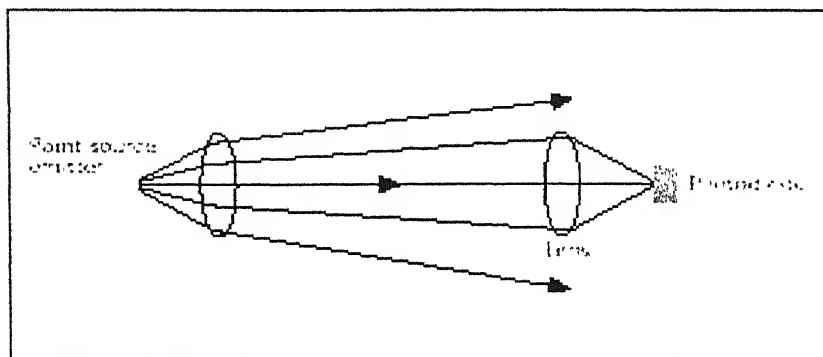


Fig 1.2 Schematic representation of free space loss

Another phenomenon that is experienced in optical wireless systems is Signal fading. This can be observed in both indoor and outdoor systems. It occurs due to the multipath signal reception by the receiver, some of them interfere destructively i.e. out of phase, so that the received power decreases due to multipath propagation environment

1.2.3 RECEIVER

The function of the receiver is to convert the optical signal back to the original electrical signal. Receivers consist of a PIN or APD photodetector, preamplifier and postamplifier circuits and a comparator to obtain digital data. PIN and APD [14] operate in reverse bias, also known as photoconductive mode of operation. The advantages of photoconductive operation are higher speed, lower capacitance, and better linearity. But since the dark current depends on the reverse bias voltage, the dark current becomes larger with increasing bias voltage.

Both photodetector and amplifier are sources of noise. The noise in a photodiode can be of two types. The first is the shot noise of the dark current, which results from the statistical uncertainty in the arrival rate of photons. The second is the thermal noise of the shunt resistance, also known as Johnson noise. Amplifier noise can be broken into three major components. The first term is the shot noise of the amplifier input bias current (I_b). Usually this current is much lower than the photodiode dark current, therefore it seldom presents a problem. The second term is the Johnson noise of the amplifier feedback resistance R_f . Since the value of the feedback resistor must be smaller than the shunt resistance of the photodiode, this term dominates the amplifier noise. The third term arises from the input voltage noise of the amplifier. The voltage noise current is interesting in that it is very dependent on the terminal capacitance of the detector. It also is very closely related to the bandwidth. The total detector-amplifier noise is combination of all the noise sources.

The important requirements on the photodiodes for wireless communications are: high quantum efficiency, fast response time, low capacitance, low dark current, and low avalanche excess noise (in case of an avalanche photodiode) as shown in Table 1.3. For APD, the dark current comprises of two components: I_{du} and I_{dm} . I_{du} is the dark-current component that is not subject to the avalanche multiplication process. It consists of mainly surface leakage current. The other component (bulk dark current) undergoes the multiplication process and denoted as I_{dm} (primary component). The total dark current is the combination of these two dark currents. Transimpedance designs are most common for optical fibre receivers due to the good compromise between bandwidth and noise (which in turn is a function of the photodiode capacitance) and superior dynamic range. Optical wireless receivers must use photodiodes with large active area. Hence designs that are tolerant of high input capacitances are required. Combining Transimpedance design with bootstrapping is a common approach. Studies show that sensitivity improves as the photodiode area reduces due to the correspondingly smaller capacitance.

Table 1.3 Typical Characteristics of State-of-the-art Photodetector

	InGaAs PIN	Ge APD	InGaAs APD	Si APD
QUANTUM η EFFICIENCY	0.8	0.8	0.8	0.8
RESPONSE TIME t_r (ps)	60	100	100	100
CAPACITANCE C_d (pF)	<0.5	<1	<0.5	<1
DARK CURRENT I_{du} (nA)	1-5	50-500	1-5	1
DARK CURRENT I_{dm} (nA)	-	50-200	1-5	1

APD receivers give about 10 dB sensitivity [15] advantage over a corresponding PIN receiver. APD receivers are more costly, is very temperature sensitive and require high operating voltages. Hence used only in specialist systems PIN receivers are the choice for systems with lower costs. Dark current and excess noise levels are higher in APDs.

In Optical wireless systems is required to design the receivers that achieve a high SNR in the face of steady background illumination. A well designed receiver will be shot-noise-limited under conditions of bright illumination. Under these conditions, it is appropriate to utilize a PIN photodiode, rather than an APD which is used when background illumination is weak. It is desirable to use a large-area photodetector since shot-noise-limited SNR is proportional to the detector area. However, large-area detectors have high capacitance, which can limit receiver bandwidth and greatly increase receiver thermal noise. It is desirable to reduce the required physical detector physical area by use of an optical concentrator, which accepts light from a large collection area and concentrates it to the somewhat smaller detector area. One type of concentrator, the dielectric compound parabolic concentrator (CPC), has been used in prototype free-space infrared links.

Guidelines for Choosing the Correct Detector

- *Try to use the smallest active area possible.* If the light source for the application is diffuse, this might not be practical but from the standpoint of noise, small diodes have lower capacitance and dark current [16]. They are also less expensive
- *In most applications, small capacitance will be more important than small dark current.* Furthermore, the NEP (noise equivalent power) in the catalogs does not take

capacitance into account; therefore care should be exercised when comparing detectors using NEP.

- *In low-bandwidth applications, photodiodes operating in a photovoltaic mode will generally outperform device-operated in photoconductive mode.* To reduce noise, the detector shunt resistance should be much greater than the feedback resistance
- *To reduce the Johnson noise, use as large a feedback resistor as possible in the first amplifier stage.*
- *In wide-frequency-bandwidth applications, PIN photodiodes operating in the photoconductive mode are preferred because of lower terminal capacitance.* APDs, with their internal gain, also perform well in wide band applications. They should be considered when the light source is weak and the amplifier noise is large.

Another problem faced by receivers is the interference from ambient light. This is a problem due to the wide field of view (aperture) of a free space optical receiver, because of which stray light gets into the photodiode in addition to the wanted optical beam. Ambient light raises the level of photonic noise [17,18] in the receiver and hence can impair performance. Knowing the properties of the ambient light sources, good remedies, such as the following are possible:

- Placing a narrow band IR filter over the photodiode to filter out majority of the ambient light
- Using a line code that contains no low frequency components (the PSD of the ambient induced noise extends from DC to tens of kHz).
- Designing the receiver to cancel or block DC (the ambient light has strong DC content).

1.3 MOTIVATION FOR THE PRESENT WORK

Despite the advances in power and performance of data communication systems, thanks to modern solid-state electronics, we are still troubled with the problems - physical, logistical, and financial – of wire- and cable-based communications within buildings. Installation, maintenance and changing cables is a nightmare. What is needed is a high performance, easy-to-deploy, user-transparent, reliable, wireless in-building communication technology. Such a system would also have to be compatible with performance, standards, and protocols of present and future cable-based voice/data communications.

The idea of using the optical medium for wireless communication is not new, having been proposed as a means for indoor communications almost two decades ago. However, the last few years have seen an explosive interest in the potential for free space optical systems to provide portable data communications. One of the prime motivators for reconsidering the use of an optical carrier in the wireless context is the demand for greater transmission bandwidths.

The radio frequency spectrum is already exceedingly congested and frequency allocations of sufficient bandwidths are extremely hard to obtain. Further, for the high bandwidth services envisaged, the use of microwave or millimeter wave systems will be required, where device technology is currently expensive or immature. Hence optical medium is the only cost-effective way to provide high bit-rate mobile services to volume markets.

Several modes of infrared transmission are possible for indoor optical wireless systems. These systems may be classified according to the degree of directionality of transmitter and receiver etc. A transmitter and receiver may have a narrow or broad radiation pattern or field of view (FOV) and can be combined to make directed, non-directed, or hybrid systems. These systems may also be classified as a line-of-sight (LOS) or nonline-of-sight (non-LOS) depending on whether or not they rely on the existence of a directed path between transmitter and receiver

In general, directed LOS links minimize path loss and maximize power efficiency, and they can achieve higher transmission rates. Such systems are referred to as Directed beam Infrared systems (DBIR). For indoor applications the distances involved are small, typically a few meters. Since the required components are less expensive and are easily available off the shelf, we decided to design and implement an experimental Irda compatible point to point link for data transmission for indoor applications, such as short distance data transfer between instruments, or from PC to PC (using RS-232 port of the PC)

1.4 STATEMENT OF THE PROBLEM

The aim of this work was to design and implement an IrDA compatible experimental point-to-point link for indoor applications. This involved the following tasks.

- Design of an Optical transmitter comprising of IR LED driver electronics, Pseudo random binary sequence generator, and encoder
- Design of Optical receiver consisting of PIN detector signals processing electronics, decoder.

- Testing of the above circuits with PRBS data for various frequencies using encoder and decoder and the measurement of maximum distance between transmitter and receiver
- Interfacing the transmitter and receiver hardware to two PCs (without encoder and decoder), and test the serial data communications on Loop back mode, Local echo mode and finally for file transfer for various baud rates using KERMIT software
- PCB design of the transmitter and receiver electronics using PROTEL PCB design software.
- Characterization of optical source and detector used.

1.5 THESIS LAYOUT

Chapter 1 gives an introduction to the work, highlighting its importance and challenges. **Chapter 2** gives a review of various Indoor optical wireless systems, system topologies, infrared LANs, limitations of IR communication, various modulation techniques for infrared systems, etc. An overview of IrDA, its various layers, data formats, and design aspects as applicable to point to point indoor links, is also given.

Chapter 3 is devoted to the design of an IrDA compatible experimental link. Design issues and system considerations of the various subsystems are also given.

Hardware implementation of the IrDA compatible Indoor point-to-point link, giving details of the various subsystems of the transmitter and receiver are given in **Chapter 4**. Performance tests carried out using the experimental link are also given.

The thesis is concluded in **Chapter 5** with conclusions and suggestions for further work. A detailed list of references used in our work is given at the end.

CHAPTER 2

REVIEW OF INDOOR OPTICAL WIRELESS SYSTEMS

The emergence of portable information terminals in work and living environments is accelerating the introduction of wireless digital links and local area networks (LANs). Portable terminals should have access to all of the services that are available on high-speed wired networks. Unlike their wired counterparts, portable devices are subject to severe limitations on power consumption, size and weight. The desire for inexpensive, high-speed links satisfying these requirements has motivated recent interest in infrared wireless communication.

As a medium for short-range, indoor communication, infrared radiation offers several advantages over radio. Infrared emitters and detectors capable of high-speed operation are available at low cost, unlimited and unregulated bandwidth, they are absorbed by dark objects, diffusely reflected by light-colored objects, and directionally reflected from shiny surfaces. They penetrate through glass, but not through walls or other opaque barriers, so that infrared transmissions are confined to the room in which they originate. This signal confinement makes it easy to secure transmissions against casual eavesdropping, and it prevents interference between links operating in different rooms. Thus, infrared wireless LANs can potentially achieve a very high aggregate capacity and their design may be simplified, since transmissions in different rooms need not be coordinated. Infrared links employ intensity modulation and direct detection (IM/DD), the short carrier wavelength and large-area, coupled with the use of square-law detector lead to efficient spatial diversity that prevents multipath fading. By contrast, radio links are typically subject to large fluctuations in received signal magnitude and phase. Freedom from multipath fading greatly simplifies the design of infrared links.

The infrared medium is not without drawbacks, however. Because infrared cannot penetrate walls, communication from one room to another requires the installation of infrared access points that are interconnected via a wired backbone. In many indoor environments there exists intense ambient infrared noise, arising from sunlight, incandescent lighting and fluorescent lighting, which induces noise in an infrared receiver. In virtually all short-range, indoor applications, IM/DD is the only practical transmission technique. The signal-to-noise ratio (SNR) of a direct-

detection receiver is proportional to the square of the received optical power, implying that IM/DD links can tolerate only a comparatively limited path loss. Often, infrared links must employ relatively high transmit power levels and operate over a relatively limited range. While the transmitted power level can usually be increased without fear of interfering with other users, transmitter power may be limited by concerns of power consumption and eye safety, particularly in portable transmitters. Radio and infrared are complementary transmission media, and different applications favor the use of one medium or the other. Radio is favored in applications where user mobility must be maximized or transmission through walls or over long ranges is required and may be favored when transmitter power consumption must be minimized. Infrared is favored for short-range applications in which per-link bit rate and aggregate system capacity must be maximized, cost must be minimized, international compatibility is required, or receiver signal-processing complexity must be minimized. A comparison of radio and infrared mediums is given in Table 2.1.

Table 2.1 Comparison of Radio and Infrared Properties

Property of Medium	Radio	Infrared
Multipath fading	Yes	No
Multipath dispersion	Yes	Yes(diffuse)
Bandwidth limitation	Regulatory	Photodiode/Preamplifier,diffuse channel
Dominant noise source	Other user interferences	Ambient light level
Range/coverage	High	Low
Security	Low	High
Spatial diversity	Possible	No
Frequency diversity	Unlikely	Impractical
Technology cost	Relatively high	Potentially low

2.1 INDOOR OPTICAL WIRELESS SYSTEM TOPOLOGIES

To date, four generic system configurations [19] have been proposed to support a variety of indoor infrared user models or envisaged application scenarios, namely

- Line-of-sight (LOS) syetms
- Wide-LOS or cellular systems

- Diffuse systems
- Tracked systems

2.1.1 LINE-OF-SIGHT SYSTEMS

Line-of-sight systems employ high degree of directionality of the transmitter and receiver and uninterrupted line-of-sight (LOS). These systems are also called **Directed links** since they employ directional transmitters and receivers, which must be aimed in order to establish a link. LOS link design maximizes power efficiency and minimizes multipath distortion. The performance of the link relies upon the existence of an uninterrupted LOS path between the transmitter and receiver. As there is no mobility, the beam aperture angle and the field of view (FOV) of the emitter and receiver, respectively, can be reduced and power losses are minimized. In the limit we can establish a parallel beam, reducing the loss due to beam spread to almost zero. The main drawback is the lack of mobility, and the susceptibility to blocking by personnel. Very narrow beams also cause pointing problems. The beamwidth should be chosen so that any inexperienced operator should be able to aim the transmitter lens towards the receiver unit by hand adjustment. Also normal vibrations or inadvertent impacts on the desk should not misalign the beam by a major fraction of a beamwidth. This implies that beamwidths cannot be smaller than one degree.

These systems have relatively low transmit-power requirements since the power is concentrated into a narrow optical beam, which maintains a high power flux density at the receiver. LOS systems do not suffer the derogatory effects of a multipath environment. Also, the receiver in an LOS system does not require a large field of view and so the effective gain of the concentrator can be exploited to improve the link budget. In addition, narrowband thin film optical filters can be readily employed because the angular dependence of the filter response is not an issue. However such systems require accurate alignment and are particularly susceptible to blocking. The optical sources must be Class 1 eye safe; hence LEDs will have to be used in place of LDs, which limits the capacity to a few megabits per second. These systems do not require weather proofing etc. and hence can be produced very cost effectively.

In recent years, the application of directed beam infrared (DBIR) or LOS communications to wireless information networking has been investigated and some products using this technology have appeared in the market. With this mode of radiation, the transmitted radiation pattern must be adjusted in the direction of the receiver.

The advantages of this method relative to Diffused links are

- It requires less optical power for reliable communications
- It does not suffer from extensive multipath and
- It can handle bi-directional communications better than diffused radiation

As a result, higher data rates and better area coverage can be achieved with this method. The disadvantages are the need for terminal alignments and the severe interruption caused by shadowing. Consequently, the DBIR method is typically used for applications in which the terminals are relatively fixed, such as desktop computers in an office. The LEDs are usually positioned high on posts to avoid shadowing. Personnel in the area are cautioned to avoid direct eye exposure in this kind of installation.

One of the most widely adopted standards to date is the **Infrared Data Association (IrDA)** standard, which is based on a short range 'point-and-shoot' philosophy. IrDA is an 'industrial club' formed in 1993 whose aim is 'to create an interoperable, low cost, low power, half-duplex serial data interconnection standard that supports a walk-up, point-to-point user model that is adaptable to a wide range of appliances and devices'. The version 1.0 of IrDA standard specifies the physical layer (SIR – serial infrared), the link access protocol (IrLMP) and link management protocol (IrLMP). The physical layer specified a 115.2 kb/s half-duplex, asynchronous link using on-off keying (OOK), allowing the transceiver to exploit the universal asynchronous receiver-transmitter (UART) inherent in the I/O of most computers. The link is specified to support bit error rates (BER) of $\leq 10^{-9}$ at ranges of ≤ 1 m using an operational wavelength of 850-900 nm, so that advantage could be taken of readily available, low cost sources and detectors. The field of view is specified between a minimum of $\pm 15^\circ$ to a maximum of $\pm 30^\circ$. Higher speed extensions work at 1.152 Mb/s, where the functionality of the UART is replaced by a communication controller and at 4 Mb/s where a pulse position modulation (PPM) format is used [].

2.1.2 WIDE-LOS SYSTEMS

These systems employ wide-angle transmitters and receivers and are also referred to as **non directed links**. They are convenient to use, particularly for mobile terminals, since they do not require aiming of the transmitter or receiver. These links generally rely upon reflection of the light from the ceiling or some other diffusely reflecting surface. They increase link robustness and ease

of use, allowing the link to operate even when barriers, such as people or cubicle partitions, stand between the transmitter and receiver.

These links have been proposed for applications such as optical telepoints and cellular coverage of large areas. Wide LOS systems increase the potential coverage area at the cost of reducing the power flux density at the receiver for a given range and transmit power when compared with an equivalent LOS system. In a typical configuration, a base station is located in the ceiling to provide coverage to the mobile units within the cell. The potential for multipath interference increases with increasing coverage area (effectively increasing the transmitter beamwidth). The receiver can still employ a relatively narrow field-of-view (FOV) detector and use thin film filters. A natural extension of wide-LOS configuration is the idea of a cellular system where coverage over a wide area is achieved using a number of base stations located in the ceiling. Computer generated holograms are particularly attractive. In addition to defining coverage area accurately, they also allow the source to be extended so that it operates in the diffuse regime for eye safety considerations. However, wide-LOS systems still suffer blocking problems. This can be solved to an extent if the cellular idea is employed where base stations co-operate. Thus if the line-of-sight path to one base station is blocked, a user may be able to use a base station associated with a different cell that is unblocked. However, system complexity and cost is increased accordingly.

2.1.3 DIFFUSE SYSTEMS

The greatest robustness and ease of use are achieved by the non-directed, non-LOS link design, which is often referred to as a **diffuse link**. However, diffuse systems have a higher path loss than their LOS counterparts, requiring higher transmitter power and a receiver having large light collection area.

This type of topology overcomes the blocking problem by relying on their high reflectivity of common building materials, so that a significant fraction of the received signal arrives at the receiver from a number of angles. Such a topology is extremely flexible and can be used in either organized (star) or ad-hoc (mesh) networks. However, the ultimate unequalized bit rate that can be supported by the link due to intersymbol interference is limited to approximately 260 Mb/s. For a coverage volume of 10x10x3 m, this would limit the unequalized data rate to around 16 Mb/s. In addition, optical losses associated with the link are much greater than those for either the LOS or wide-LOS cases. One can characterize the wideband diffuse channel using a network-analyser

swept frequency technique. Link losses for a typical configuration were found to be on the order of 120-130 dB, while the r.m.s delay spread was approximately 12 ns. The receiver design is made more demanding because of the high dynamic range requirements due to the large variations in received signal level

In the case of an entirely diffuse link, the optical power is launched into a closed room to be scattered by the walls, ceiling, floor, and furniture. After some reflections, the irradiance is almost uniform, so that the detector does not need to be oriented toward the emitter. Full mobility within the room is allowed and there are no shadowing effects caused by moving persons or machines. There are two limitations for diffuse links: the emitted optical power has to be large enough to cover the whole volume and multipath dispersion limits the data rate. Multipath propagation causes a spread of the transmitted pulse, which may result in a loss of pulse amplitude and intersymbol interference. There is therefore, a maximum transmission speed, which depends on the room size and the reflection coefficients of the surfaces inside the room.

2.1.4 TRACKED SYSTEMS

These systems offer potentially high bit rates and combine the high power flux densities associated with LOS systems with the increased coverage enjoyed by wide-LOS systems. In a typical scenario, a narrow LOS beam from a base station located in the ceiling illuminates the mobile unit. This 'spotlight' beam is steerable and so can track the mobiles as they move around the coverage area. Similarly, a steerable beam at the mobile would be required if the data rate on the link is to be reciprocal. To date, beam steering has been achieved by means of steerable optics. In a practical system, the tracking functionality must be realized in solid state using arrays of emitters and detectors.

2.2 INFRARED LANs

Broadly speaking, IR LANs use either directed-beam or diffused radiation. In the past decade, most of the development efforts in wireless optical LANs have been concentrated on diffused infrared (DFIR) radiation. The advantage of this mode of radiation is that it does not require a direct line of sight between the transmitter and the receiver, since the receiver can collect a transmitted signal through reflections from the walls, ceiling, or other objects in the room. Therefore, the installation of the network does not require alignment to establish the communication

link, and this provides portability of the terminal. The disadvantages relative to directed-beam radiation are:

- DFIR requires higher power to cover a given area.
- Multipath limits the data rates.
- There is higher risk for eye exposure, and
- In simultaneous two-way communications, each receiver collects its own transmitted reflections, which are sometimes stronger than the transmitted signal from the other end of the connection.

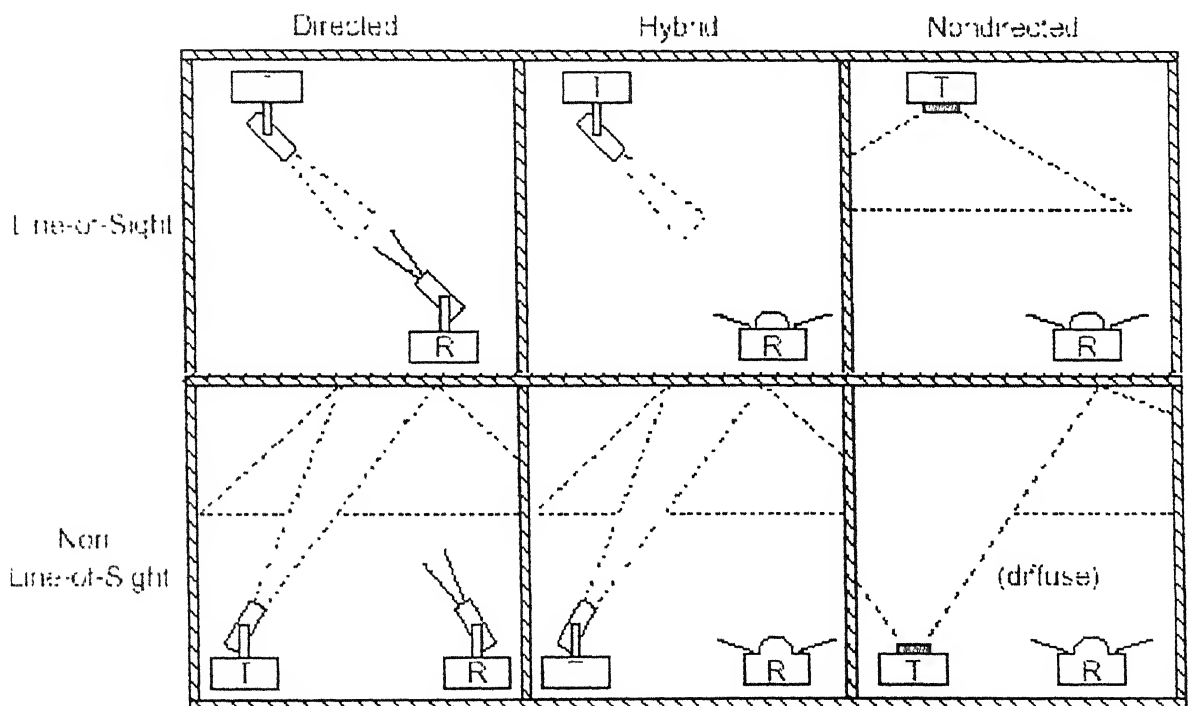


Fig. 2.1 General Classification of Indoor Optical Wireless Systems

As a result, DFIR networks tend to be used primarily for applications demanding portability, such as cordless phones or communication with laptop or pen-pad computers.

In recent years, the application of directed beam infrared (DBIR) communications to wireless information networking has been investigated and some products using this technology

have appeared in the market. With this mode of radiation, the transmitted radiation pattern must be adjusted in the direction of the receiver. The advantages of this method relative to DFIR are

- It requires less optical power for reliable communications
- It does not suffer from extensive multipath, and
- It can handle bi-directional communications better than diffused radiation.

As a result, higher data rates and better area coverage can be achieved with this method. The disadvantages are the need for terminal alignments and the severe interruption caused by shadowing. Consequently, the DBIR method is typically used for applications in which the terminals are relatively fixed, such as desktop computers in an office. The LEDs are usually positioned high on posts to avoid shadowing. Personnel in the area are cautioned to avoid direct eye exposure in this kind of installation.

A third method of transmission for optical networks is Quasi-Diffused IR (QDIR). With this method the terminals communicate using an active or passive reflector. Each terminal communicates with the reflector using a directed beam. Passive reflectors are mirror-like devices with high scattering and reflecting properties. The active reflector amplifies and rebroadcasts the received signal. Passive reflectors require more transmission power from the terminals but they avoid the installation and maintenance problems associated with the active reflectors.

Table 2.2: A Comparison of Available Wireless LANs

Technique	DFIR	DBIR	RF
Data rate:	1 Mb/s	10 Mb/s	15 Mb/s
Mobility:	Good	None	Better
Detectability:	Negligible	Negligible	Some
Range:	70-200 ft	80 ft	40-130 ft
Frequency/Wavelength	$\lambda=800-900$ nm	$\lambda=800-900$ nm	$f=18$ GHz
Radiated Power:	-	-	25 mW

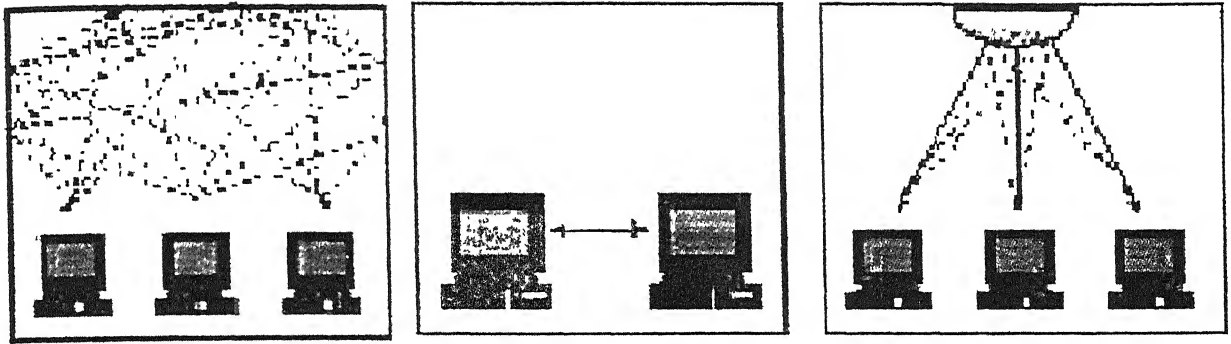


Fig. 2.2 Specified Classification of Indoor Optical Wireless Systems

2.3 LIMITATIONS OF IR COMMUNICATIONS

Wireless indoor infrared (IR) transmission systems have been used in many applications in the past few years, ranging from simple remote controllers for home appliances to more complex wireless local area networks. The performance of IR transmission systems is impaired by several aspects such as the speed limitations of the optoelectronic devices (LEDs and PIN photodiodes), the high path loss that leads to the requirement for transmission of high optical power levels, the multipath dispersion, the receiver noise, the shot noise induced by the background ambient light and the interference induced by the artificial light sources.

Shot Noise from ambient lights can be suppressed by inserting a narrowband optical filter before the photodetector. However, implementing such a filter with a wide field of view is difficult. An costly alternative would be to use nonplanar (e.g. hemispherical) dielectric shells to achieve a wide field of view, omnidirectional, narrow band filter. Low-frequency noise from fluorescent lights can be avoided with the use of a line code or a subcarrier to move the signal spectrum away from dc.

In an indoor environment, an optical signal in transit from transmitter to receiver undergoes temporal dispersion due to reflections from walls and other reflectors; this dispersion causes multipath fading. Diffuse systems are more prone to multipath effects than directed-beam systems. This limits the data rate, and increases the bit error rate (BER).

The transmission speed of IR links has a basic limitation from the rise and fall times of LEDs. For example, for the Siemens LD-271 or Gilway-E14, the LED rise and fall times are about $1\mu\text{s}$, limiting data rate to 500 Kb/s.

The problems resulting from high-capacitance photodiodes can be limited by a careful receiver design that incorporates an array of APD-based transimpedance amplifiers. The effects of multipath dispersion, which cause a power penalty if left unchecked, can be reduced by using a Decision Feedback Equalization (DFE) or choosing an appropriate modulation technique.

Although, as a medium for short range, indoor communication, infrared offers many significant advantages as above, the indoor optical wireless environment is, however, far from ideal. Background radiation associated with daylight, and fluorescent and incandescent lighting induces shot noise in the detector, thus impairing transmission. Channel dispersion associated with multipath propagation is also a major issue in optical wireless links. Moreover, there are receiver-bandwidth and speed limitations imposed by the capacitance associated with large-area photodiodes. Additionally, high sensitivity detection is usually called for due to the low optical transmitter energies used (to accommodate the IEC825 eye safety requirements). Despite these impairments, commercial links such as IrDA –compliant transceivers are available and operate at up to 4 Mb/s.

At present, most infrared links are of the directed-LOS or hybrid-LOS designs. The low path loss of these designs minimizes the transmitter power requirement and permits the use of a simple, low-cost receiver. Typically, these links transmit using a single light-emitting diode (LED), which emits an average power of several tens of mW that is concentrated within a semiangle of 15° - 30° . The LED emission wavelength typically lies between 850 and 950 nm. This wavelength matches the responsivity peak of the silicon PIN photodiode. Directed-LOS links employ an optical concentrator that restricts the FOV, usually with the goal of providing a higher degree of optical concentration. Directed-LOS are relatively free from multipath distortion, sometimes permitting them to achieve bit rates above 100 Mb/s while maintaining a very simple design. These links designs are well suited for point-to-point and some point-to-multipoint applications, but are not suited for multiple-access networks, since it is difficult to establish full bi-directional connectivity between more than two transceivers.

2.4 MODULATION TECHNIQUES USED IN INDOOR IR SYSTEMS

Modulation techniques for radio wireless systems include amplitude, phase and frequency modulation (AM, PM and FM), as well as some generalizations of these techniques. Radio receivers employ one or more antennas, each followed by a heterodyne or homodyne down converter, which is comprised of a local oscillator and a mixer. Efficient operation of this mixer relies upon the fact that it receives both the carrier and the local oscillator in a common electromagnetic mode. The down converter output is an electrical signal whose voltage is linear in the amplitude of the received carrier electric field

In a low cost wireless infrared system, it is extremely difficult to collect appreciable signal power in a single electromagnetic mode. This spatially incoherent reception makes it difficult to construct an efficient heterodyne or homodyne down-converter for AM, PM or FM, or to detect AM, PM by any other means. For infrared links, the most viable modulation is *intensity modulation* (IM), in which the desired waveform is modulated onto the instantaneous power of the carrier. The most practical down-conversion technique is *direct detection*, in which a photodetector produces a current proportional to the received instantaneous power, i.e., *proportional to the square* of the received electric field.

Wireless infrared links are based on ***intensity modulation and direct detection (IM/DD)*** of the optical carrier. Intensity modulation is performed by varying the current of a laser diode or an LED. Direct detection is performed by PIN photodiodes or APDs that produce an electrical current proportional to the incident optical power. The opto-electronic components used more frequently are LEDs and PIN photodiodes. The signal-to-noise ratio (SNR) of a direct-detection receiver is proportional to the square of the received optical power, implying that IM-DD links can tolerate only comparable limited path loss.

The intensity-modulated direct detection (IM-DD) channel in optical wireless systems differs from the conventional channel in two ways. First, in the IM-DD channel, the input to the receiver cannot be negative. Secondly, it is the average input amplitude that is constrained, whereas in the conventional channel it is the average power that is restricted. This is because the input signal to the infrared receiver represents power, which is then converted into a photocurrent. In practice, there will be some restriction on average transmission power due to eye safety

considerations. Thus, modulation schemes that operate efficiently in the conventional channel may not necessarily be suited to the IM-DD channel.

The most important criterion for evaluating modulation techniques is the average received optical power required to achieve a desired BER. At high bit rates, one must consider the effect of multipath ISI on this power requirement, as well as any reduction of the ISI that can be achieved through techniques such as adaptive equalization. The second most important attribute is the receiver electrical bandwidth requirements, as it can be difficult to achieve flat frequency response and low noise over a wide bandwidth using large area photodiodes. Other important criteria for comparison of modulation techniques are the complexity and power consumption of a portable receiver.

There are several modulation and/or encoding schemes that are suitable for optical wireless systems [23]. The simplest approach, based on intensity modulation with direct detection, is on-off keying (OOK). The use of RZ pulses in OOK having certain duty cycle increases the bandwidth requirement. However, it decreases the average power requirement, because the increased noise associated with this expanded bandwidth is outweighed by the increase in peak optical power.

For this reason, OOK with RZ pulses is utilized in a number of current infrared systems. However, when the pulse duty cycle is made sufficiently small, it becomes more efficient to encode information in its position i.e., to use Pulse Position Modulation (PPM).

Coherent optical modulation techniques, in which either the phase or the frequency of the roughly 3×10^{14} Hz optical carrier is modulated directly, will not be considered because of the high complexity required to implement a coherent optical receiver. Intensity modulation is simpler, and thus a more cost-effective technique.

Higher average power efficiency can be achieved by employing **pulse modulation** schemes in which a range of time-dependent features of a pulse carrier may be used to convey information. PPM is a technique that achieves higher average power efficiency than OOK at the expense of increased bandwidth requirements. However, the use of PPM increases system complexity compared to OOK, since both slot- and symbol-level synchronization are required at the receiver, and are critical to system performance.

L-level pulse position modulation (L-PPM) was originally developed for long-haul point-to-point optical fibre links due to its high power efficiency. In this scheme, M bits of data are conveyed by a single pulse in one of $L=2^M$ positions. For $M=2$, it is usual practice to leave a temporal guard band at the end of each frame to minimize interframe interference. L-PPM offers improved power efficiency compared with simple NRZ schemes at the expense of reduced bandwidth efficiency.

PPM is an orthogonal modulation scheme that offers a decrease in average-power requirement compared to OOK, at the expense of an increased bandwidth requirement. L-PPM utilizes symbols consisting of L time slots, which are referred to as *chips*. A constant power is transmitted during one of these chips and zero is transmitted during the remaining $L-1$ chips, thereby encoding $\log_2 L$ bits in the position of the “high” chip. For a given bit rate, L-PPM requires more bandwidth than OOK; for example, 16-PPM requires four times more bandwidth than OOK. In the absence of multipath distortion, L-PPM yields a decrease in average-power requirement that decreases steadily with increasing L ; making PPM suitable for portable infrared transmitters. PPM can achieve much greater immunity than OOK to near-d.c noise from fluorescent lamps. In addition to the increased bandwidth requirement, two drawbacks of PPM, as compared to OOK, are the increased transmitter peak-power requirement, and the need for chip-and symbol-level synchronization.

Differential Pulse interval modulation (DPIM): In this scheme each symbol is transmitted as a pulse of one time slot duration, located in the k th slot after the preceding pulse, where k is determined by the data word to be transmitted. Hence, each frame consists of a fixed duration pulse that is displaced from the pulse in the preceding frame by a number of timeslots proportional to the data word. As the frame length is variable, DPIM offers improved transmission capacity over PPM. Also when compared with PPM the scheme is more robust to jitter and timing extraction at the receiver is simpler. However, errors will tend to be grouped as correctly demodulating a symbol relies on the successful demodulation of the previous symbol.

2.5 IrDA STANDARDS FOR INDOOR OPTICAL WIRELESS SYSTEMS

One of the major developments in recent years has been the arrival of very short distance (1m or less) “point and shoot” optical wireless systems for laptop computers, PDAs, palmtops,

printers, calculators, and mobile phones. These wireless systems are commonly referred to as IrDA systems in recognition of the **Infrared Data Association (IrDA)** standard that they embody. IrDA was established in 1993 with the aim of producing an open standard for wireless Data communication using mature, commercially available infrared components. The resulting protocol provides a simple, low-power, low-cost, reliable means of wireless infrared communications for a broad range of computing, communications, and consumer devices.

The initial IrDA 1.0 specification detailed a serial, half-duplex, asynchronous system with transfer rates of 2400 bits/s to 115.2 kbits/s at a range of up to 1 meter with a viewing half-angle between 15 and 30 degrees. IrDA has extended the physical layer specification to allow data communication at transfer rates up to 4 Mb/s.

IrDA chose the short-range, walk-up, point-and-shoot directed infrared communication model for two main reasons. First, it was perceived that the initial target market for IrDA-enabled devices would be mobile professionals who are also computer users. The environment for use of such devices would be in a typical working environment in which the majority of stationary devices, such as printers or computers, would be located within the user's own reach space, on the desktop or in the immediate vicinity. Typical use of such devices would be such as file transfer or printing. Such use scenarios do not require the devices to be continually connected to each other, and a directed model of communications was adopted in which the user consciously points the infrared device at the target. IrDA provides standards for ubiquitous access to such devices.

Second, IrDA chose this communication model to minimize cost. The use of a single LED and photodiode in the transceiver enables extremely low-cost implementation. The model simplifies the protocol by restricting the number of visible devices, hence limiting the contention and interference between IrDA devices. The limited range also allows reuse of the infrared wavelength, allowing multiple pairs of devices to communicate at the same time, located in the same room at some distance.

IrDA aimed to allow its standards to support a wide class of computing devices and peripherals that might be used by mobile professionals. These devices would range from very sophisticated, high-power notebook or laptop personal computers, through palmtop computers and personal digital assistants, to simple single-function devices like electronic business cards or phone dialers. Target peripheral devices would include conventional computer-oriented devices like

printers and modems, as well as automatic teller machines and public and mobile telephones. To target such a broad range of devices, a set of general requirements was placed on any prospective standard. These requirements included:

- Low cost
- Industry standard
- Compact, light weight, low power
- Intuitive and easy to use
- Non-interfering

Based on these requirements, the IrDA committee developed a series of standards aimed at providing ubiquitous, low-cost, directed infrared communications for all classes of mobile computing devices. The core of the IrDA standards are Infrared Physical Layer Specifications (IrPHY), Infrared Link Access Protocol (IrLAP), Infrared Link Management Protocol (IrLMP). These specifications are briefly discussed below.

2.5.1 INFRARED PHYSICAL LAYER SPECIFICATIONS (IrPHY)

IrPHY specifications [] describe an infrared transmission system based on a UART modulation strategy. It specifies the necessary parameters to provide an asynchronous half-duplex serial communications link over distances of at least one meter at data rates between 2.4 kb/s and 4 Mb/s. The cone half-angle of the infrared transmission is specified as being between 15° and 30°. Links operating at bit rates of 115.2 kb/s and below employ OOK with RZ pulses having a duty cycle of 0.1875. The high bit rate 4 Mb/s links utilize on off keying (OOK) with return to zero (RZ) pulses having a duty cycle of 0.25. IrDA-complaint transmitters must emit at a wavelength between 850 and 900 nm into a semi-angle (at half-power) of 15° - 30°. Compliant receivers must have a FOV (semiangle at half-effective light-collection area) of at least 15°. IrDA links are required to achieve a bit error rate (BER) not exceeding 10^{-9} over a range of at least 1m. There are several modes specified for the IrPHY, viz., Serial Infrared (SIR), Medium Infrared (MIR) and Far Infrared (FIR). Baud rates, modulation format and other characteristics of these modes are compared in Table 2.3.

Table 2.3 Different Modes Available in IrPHY Layer

IrPHY modes	Baud Rates	Modulation Format	Packet Framing	Software	Clock Recovery	Hardware
Serial Infrared (SIR)	24 - 115.2 Kb/s	UART based RZ, 3/16 bit time pulse duration	Character Stuffed	Packet Framing CR calculation	UART	ENDEC, Transceiver HPF
Medium Infrared (MIR)	Up to 115.2 Mb/s	RZ Synchronous Communication controller based	HDLC bit stuffing	Higher level protocols	Synchronous communication controller	Packet framing, CRC generator & Checking
Far Infrared (FIR)	Up to 4 Mb/s	4 PPM	Frame packets with sequence code violations	Higher level protocols	PLL based for recovering the sampling clock from the received signal	Packet framing, CRC generator & checking

2.5.2 INFRARED LINK ACCESS PROTOCOL (IrLAP)

The IrLAP protocol is derived from an existing asynchronous data communication standard, the high level data-link control (HDLC) protocol. IrLAP utilizes most of the standard frame types defined by HDLC []. IrLAP links may be point-to-point or point-to-multipoint. A key feature of IrLAP is that when a link is established, a negotiation process defines one node as primary, and all other nodes as secondary. All transmissions over the link must go to, or from, the primary node. IrLAP defines procedures for link initialization, device address discovery, connection start-up (including bit-rate negotiation), data exchange, disconnection, link shutdown, and device address conflict resolution

2.5.3 INFRARED LINK MANAGEMENT PROTOCOL (IrLMP)

This protocol provides the means for multiple software applications running in each node to operate independently and concurrently, sharing the single link provided by IrLAP between the primary node and each secondary node. This involves three processes: discovery of the services that the link currently has, multiplexing (LM-MUX) of the communications of several applications

over the single link, and management of the link, including provision for applications that demand exclusive use of the link (LM-IAS).

2.5.4 OTHER IrDA STANDARDS

The three standards described above, – IrPHY, IrLAP, and IrLMP form the core of the IrDA architecture, and all are required for a device to be IrDA compliant. In addition to the base standards, IrDA has specified a protocol called Tiny TP. This protocol is an extremely lightweight transport protocol designed to provide application-level flow control as well as segmentation and reassembly of application data units. This protocol has proved to be useful and is now implemented by most applications that support the IrDA architecture.

The original target for IrDA was cable replacement. The need for a protocol to support the redirection of serial and parallel cable traffic resulted in the IrCOMM serial parallel port emulation protocol specification. This protocol enabled the redirection of conventional serial and parallel ports over the infrared medium, allowing many existing applications to operate unchanged over an IrDA link. Another area seen as a suitable application of IrDA, particularly as a result of the high-speed extensions, is wireless access to local area networks. The protocol IrLAN was developed to allow an IrDA-enabled device to access a LAN over the infrared medium. The protocol, in combination with an IrLAN-compatible LAN access device, provides the IrDA device with the equivalent functionality of a LAN card and the advantages of wireless connectivity.

IrDA-transceivers are now an integral feature of numerous portable and fixed information appliances, including laptop computers, personal digital assistants, printers, and wireless access points to wired networks. It is also envisioned that IrDA transceivers will be incorporated into cellular and desktop telephones, pagers, watches, digital cameras, automobiles, public telephones, automatic teller machines, information kiosks, and industrial machinery, enabling new applications of short range wireless communication.

CHAPTER 3

DESIGN OF IrDA COMPATIBLE INDOOR POINT-TO - POINT EXPERIMENTAL LINK

This chapter gives the design details and system considerations for the implementation of an IrDA compatible indoor point-to-point experimental link. The sub systems to be designed are the transmitter, consisting of the encoder and source-driver electronics, and the receiver, consisting of the decoder, receiver. System considerations involved in the selection of the sub-system components are detailed below.

In our design we consider a Asynchronous half-duplex serial infrared (SIR) communications link with data rates in the range of 9.6 – 57.6 kb/s. For these data rates IrDA standards specify the use of Return-to-Zero-Inverted (RZI) encoder and decoder with 3/16-bit time pulse duration. Zeros are represented by a pulse of 3/16-bit duration, and ones by the absence of a pulse. The code is power efficient since infrared light is only transmitted for zeros. The tall narrow pulse has better signal-to-noise ratio performance than a short wide pulse of the same energy. Infrared transmission system based on UART modulation strategy. Other design specifications for the above SIR are as follows :

- Protocol - UART compatible
- Bit error rate - less than 10^{-9}
- Bit rate - 9.6 – 57.6 kb/s
- Modulation - OOK, RZI
- Directionality - Line of sight
- Range - 10 cm, typical
- Error detection - Bit-stuffing implemented in software

3.1 SELECTION OF SUB-SYSTEM COMPONENTS

The basic subsystems of an Indoor IR link are the transmitter and the receiver. The choice of a suitable source and detector depends on cost, size, wavelength of operation and power

consumption considerations and also by the maximum safety levels (as per IEC standards), so as not to degrade the performance of the system. Further, one needs to choose a suitable receiver front end from the system requirements point of view

3.1.1 SELECTION OF OPTICAL SOURCE

Two types of semiconductor sources that are available for indoor link are LED and Laser diode. Two major constraints for selection of optical source are power requirements and eye safety. LED emits light in an incoherent manner, but are eye safe. LEDs show linear behavior in their optical power output vs. current characteristics. They are very rugged and have high life time. The availability of high power and broader bandwidth Laser diodes (LDs) at low costs is attractive, especially for outdoor applications. However, for indoor applications LDs pose a potential safety hazard, as they are point source emitters. LEDs are large-area emitters and thus can be operated safely at relatively high powers. LEDs are less expensive and less prone to damage than LDs. Another important source parameter is the optical beam radiation pattern. Typical packaged LEDs emit light into semiangles (at half power) ranging from about 20°- 40°, making them suitable for directed indoor transmitters.

LEDs utilize relatively simple drive circuits without the need for feedback to control output power, are immune from coherency related problems (pulsations, kinks, and modal noise), and operate over a wide temperature range with unparalleled reliability. To compensate for the lower powers, arrays of them can be used. However, LED's cannot be used beyond 10 Mb/s, since LEDs present large rise and fall times, and thus not compatible with the short pulses required for high data rates. In comparison LDs can be used up to at least 1Gb/s.

The wavelength of operation of the LEDs is another design consideration. Due rapid developments in fiber optic systems, the available wavelength of operation of LED and laser diode optical sources are 850nm, 1300nm and 1550nm. AlGaAs or GaAs sources emitting light in the range of 820 –900 nm are the ideal source for most applications of indoor infrared wireless links, from the cost and the available output power point of view. Further, their wavelength coincides with the peak responsivity of inexpensive, low capacitance silicon photodetectors.

When compared to LD's, LED's can offer the advantages of higher reliability, reduced temperature sensitivity, less complicated drive circuit requirements, immunity to optical feedback,

and lower cost due to high yields and simpler packaging technology. Taking into consideration all the system issues detailed above LED was chosen as the source in our indoor application

3.1.2 SELECTION OF OPTICAL DETECTOR

The important requirements on the photodetector for the optical receiver are high receiver sensitivity, wide dynamic range, bit rate transparency, bit pattern independency and fast response time, low capacitance, low dark current. Other requirements are power supply constraint, reliability, size, cost, etc. The highest bandwidth attainable is ultimately limited by the response time of the receiver. A typical response time of 10ns is generally required.

The two most widely used detectors are PIN photodiodes and Avalanche photodiodes. Both of these find wide applications in fiber optics and IR systems. The role of the light detector is to convert optical power to electrical power, independent of the energy of the transmitted light pulses and the opto-electrical conversion must be independent of the duration of the light pulses used. The most commonly employed photodetector in most of the IR communication systems is the silicon p-i-n detector, since it is relatively easy to fabricate, is highly reliable, has low noise, and is compatible with low-voltage amplifier circuits. Such a detector operates well when reverse biased. The photocurrent produced by a PIN detector is directly proportional to the incident light power level. At 900nm the typical responsivity of a silicon detector is 0.6 Amps/Watt. The responsivity relation of a detector is independent to the size of the detector.

An important detector parameter which determines the speed of the receiver is detector capacitance. In order to achieve this it is important have detectors with the smallest active area possible. Small diodes also have lower capacitance and dark current. In most applications, small capacitance will be more important than small dark current. Furthermore, the NEP in the catalogs does not take capacitance into account, and hence care should be exercised when comparing detectors using NEP.

In low-bandwidth applications photodiodes operating in a photovoltaic mode will generally outperform device-operated in photoconductive mode because of their lower terminal capacitance and higher speeds. To reduce noise, the detector shunt resistance should be much greater than the feedback resistance. In order to reduce the Johnson noise, it is important to use as large a feedback resistor as possible in the first amplifier stage. APD's, with their internal gain, also perform well in wide band applications. They should be considered when the light source is weak and the amplifier noise is large. APDs require the use of high voltage power supplies with very good regulation. The APD gain is a strong function of the operating voltage and hence these voltages

must be set very accurately. PIN photodetector based receiver was found to be the most suitable for our application.

3.1.3 RECEIVER FRONT-END SELECTION

There are primarily three receiver front-end configurations (preamplifier) that are used in optical detectors, viz. low impedance front-end, high impedance front end and transimpedance front end. The major performance parameters of receivers are their sensitivity, dynamic range and bandwidth. Sensitivity of a receiver defines the minimum optical power required to obtain a given SNR (or BER). Dynamic range gives the range of optical input power possible, and it is the ratio of the largest to the lowest input power, expressed in dB.

Low impedance front ends use a very low load resistance, typically less than 1Kohms, for the photodetector. The voltage developed across the low load impedance is then fed to further amplifying stages. These front ends give very low rise times and hence good response times, resulting in high bandwidths. Their dynamic ranges are also very good. However, these receivers are very inferior from the point of view of sensitivity due to their large noise contributions due to the low impedance front end.

In high impedance front ends the load resistance is kept as high as possible. Hence they achieve very high sensitivity and very low noise. However, they are very inferior from the point of view of both bandwidth and dynamic range. These receiver front ends are seldom used.

A good compromise between the low and high impedance designs is the transimpedance design. Transimpedance front end uses a feedback amplifier with a medium feedback resistance, R_f . The value of R_f is chosen to satisfy the noise and sensitivity requirements. Being a feedback amplifier configuration this frontend enjoys good bandwidth and dynamic range. In our design an opamp based transimpedance front end was used along with a PIN photodetector.

3.2 LIMITATIONS OF THE SYSTEM COMPONENTS

The performance of a Indoor point to point link is effected by the limitations of the system components. Since single LED was chosen as a source based on eye safety puts a limit on the transmitted power and the range attained. By using array of LEDs one could increase the output

power levels and the range too at the same time keeping in mind the eye safety levels. But the driver electronics for the array of LEDs becomes complex and care must be taken about the rise and fall times of all the LED's to match with the data transmission rates.

In order to have large coverage range the receiver used in the IR link should have extremely good sensitivity. PIN photodiode was chosen as a detector due cost and other factors. One has to be satisfied by the typical values of sensitivity offered by the PIN detector.

Another serious problem in Indoor IR systems is the presence of ambient light. This will lead to extra noise due to unwanted light. This problem can be solved to by using a narrow band filter in front of the receiver. In our application since the source and the detector are in line of sight, we did not use any optical filter, but the ambient lighting was kept minimum.

3.3 ENCODER

The receiver needs a way to distinguish between the surrounding illumination, noise, and received signal. For this purpose, it is useful to use the highest possible output power. Higher received power would mean higher current in the receiver leading to better signal-to-noise ratios. However, if a simple strategy of switching ON the LED during a logical 1 and switching it OFF during a logical 0 is adopted, the average power levels will be high and hence the average LED current requirements will be very high. Instead if the IR-LEDs are made ON only for a fraction of the bit period, much higher peak powers can be transmitted for a given average power, while maintaining lower average powers. Typically, in the pulsed mode the peak LED power generated can be up to 4 or 5 times the maximum allowed continuous power.

The basic infrared interface is built around the characteristics of a UART (Universal asynchronous receiver/transmitter), a humble component found in the serial COM ports of every personal computer. Most UARTs have several selectable bit rates, ranging from 2.4 kb/s up to 115.2 kb/s. When data is sent, the UART takes outgoing bytes and converts them to 10-bit serial characters. Each character begins with a start bit (a logical "0"), followed by 8 data bits (least bit first), and a stop bit (a logical "1"). The Infrared Data Association (IrDA) defines several protocols for sending and receiving serial infrared data, including rates of 115.2 Kb/s, 0.576 Mb/s, 1.152 Mb/s, and 4 Mb/s. The low rate of 115.2 Kb/s was specified for the Serial Infrared (SIR) physical layer. At the 115.2 Kb/s rate, the protocol implemented in the hardware is fairly simple. It primarily

defines a serial infrared data *word* to be surrounded by a start bit equal to 0 and a stop bit equal to 1. Individual bits are encoded or decoded the same whether they are start, data, or stop bits. The clock used to code or sample the data is 16 times the baud rate, or 1.843 MHz maximum. To code a 1, no pulse is sent or received for 1-bit time period, or 16 clock cycles. To code a 0, one pulse is sent or received within a 1-bit time period of 16 clock cycles. The pulse must be at least 1.6 μs wide and 3 clock cycles long at 1.843 MHz. At lower baud rates the pulse can be 1.6 μs wide or as long as 3 clock cycles as shown in Table 3.1. The transmitter output, IR_TXD, is intended to drive a LED circuit to generate an infrared pulse. The LED circuit works on positive pulses. The various data rates (signaling rates) specified by the SIR physical layer are 2.4 kb/s, 9.6 kb/s, 19.2 kb/s, 38.4 kb/s, 57.6 kb/s and 115.2 kb/s.

The role of the encoder is to receive the incoming data and encode a logical 0 in the bit stream by a 3/16 pulse and a logical 1 with no pulse. The incoming bit stream consisting of a start bit, 8 data bits, and a stop bit, is shown in Fig. 3.2. The clock used to code or sample the data is 16 times the baud rate. For a 9.6 kb/s baud rate we need a clock of $9.6 \text{ kb/s} \times 16 = 153.6 \text{ kHz}$. The minimum and nominal duration of the IrDA pulse for various baud rates are shown in Table 3. The associated timing diagram is shown in Fig. 3.2.

In Table 3.1 T_1 corresponds to the bit periods for various data rates and $T_2 = (3/16) T_1$. The IrDA specified minimum pulse duration in each case is 1.4 μs . However, nominal pulse durations in each case is given by $T_2 = (3/16) T_1$.

Table 3.1 IrDA Pulse Specifications for Various Data Rates

Transfer Rate	T_1	T_2	T_2 / T_1	IrDA Pulse Duration <i>minimum</i>	IrDA Pulse Duration <i>Nominal</i>	Radiant Intensity
9.6 Kb/s	104 μs	19.53 μs	3/16	1.41 μs	19.53 μs	40 mw/sr
19.2 Kb/s	52.0 μs	9.77 μs	3/16	1.41 μs	9.77 μs	40 mw/sr
38.4 Kb/s	26.0 μs	4.88 μs	3/16	1.41 μs	4.88 μs	40 mw/sr
57.6 Kb/s	17.3 μs	3.26 μs	3/16	1.41 μs	3.26 μs	40 mw/sr

Fig. 3.2 IrDA-Sir Encoding scheme detailed timing diagram

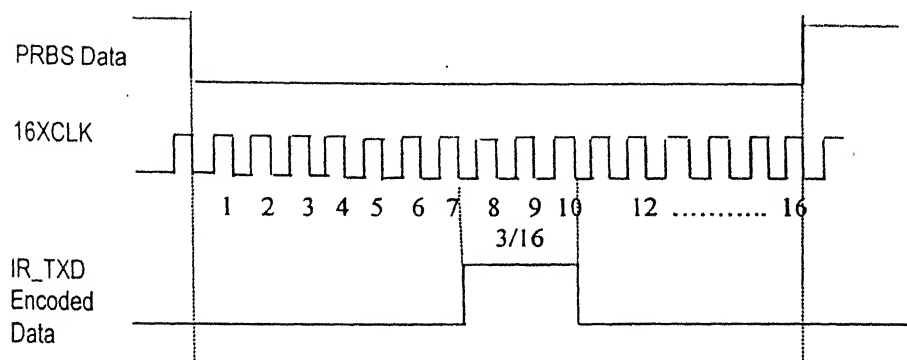
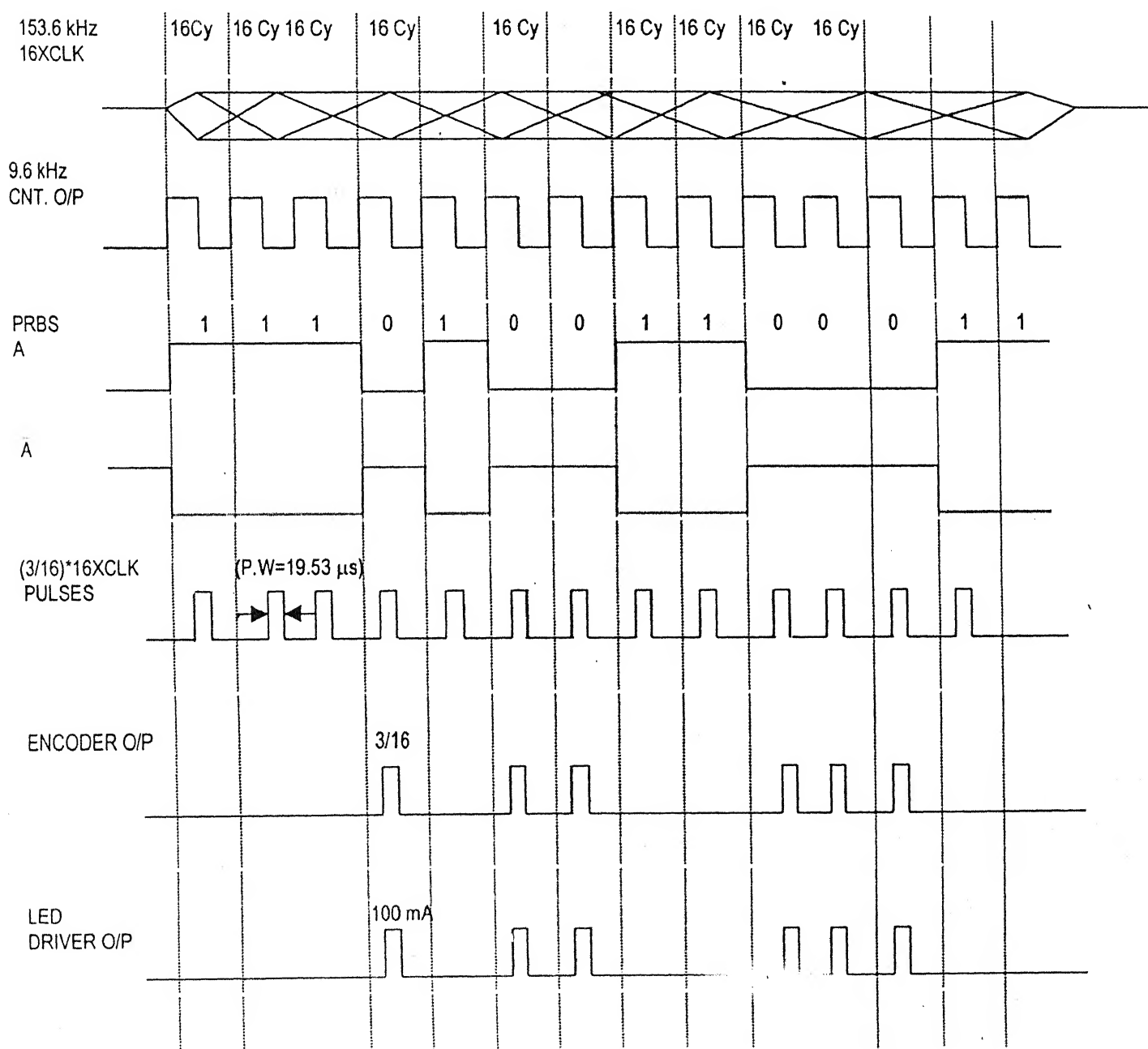


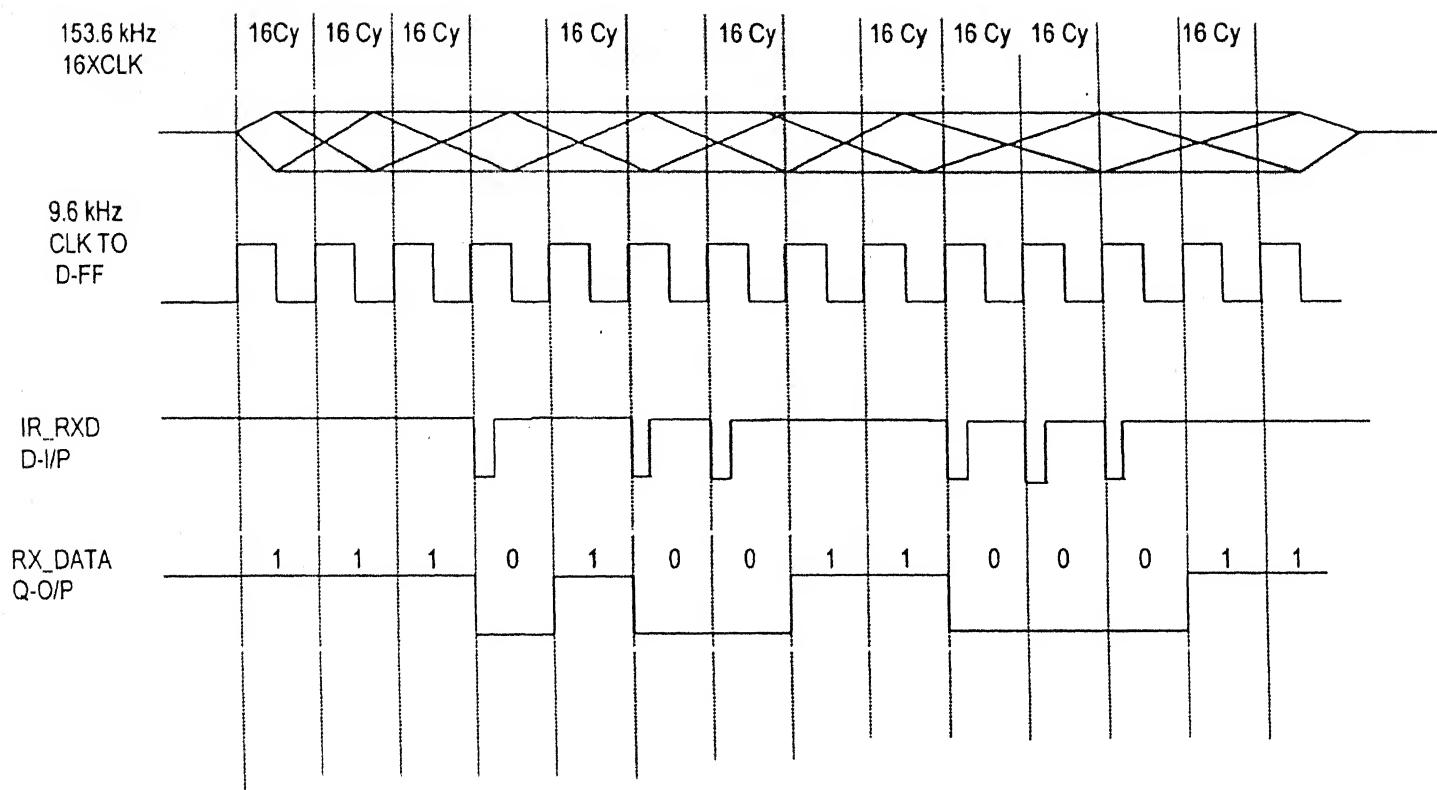
Fig. 3.2 Timing diagram of Encoder Circuit Macro view



3.4 DECODER

At the receiver, the pulses received have to be decoded to get back the original transmitted data. The decoder requires a clock that is 16 times the desired baud rate. The received IR pulses to the Input of the decoder have a pulse width of $(3/16) \times \text{baud rate}$. Whenever the falling edge of an IR pulse is detected the output of the decoder goes to low state and remains there for a period of 16 clock cycles and it signifies that a logical zero data bit has been decoded. As long as no IR pulse is received and no falling edge is detected for a duration of 16 clock cycles, the output of the decoder will interpret that a logical 1 was sent and hence it will output a logical 1. The associated timing diagram is shown in Fig. 3.2.

Fig. 3.2 Timing diagram of Decoder Circuit



CHAPTER 4

IMPLEMENTATION OF AN IrDA COMPATIBLE INDOOR POINT-TO-POINT EXPERIMENTAL LINK

This chapter gives the hardware implementation details of the indoor point-to-point link as tried out by us. We had used a single IR LED keeping in view the eye safety and power requirements as per IrDA SIR link specifications. As mentioned in the previous chapter, pulse modulation with $3/16$ of the length of the original bit rate is used by the encoder. The encoded output is passed to the IrDA transmitter where bits are translated into an infrared pulse stream, where a flash of light represents a "0" and no light signifies a "1". On the receiver side, a p-i-n diode serves as the detector, taking the light pulses and turning them into electrical energy which is amplified, and then converted back to digital data.

In the following sections implementation details of the various subsystems are explained. Measured results regarding the performance of the various subsystems are also given. Finally, details of the file transfer between two PCs carried out using the experimental link is also given.

4.1 TRANSMITTER CIRCUIT

The transmitter comprises of a pseudo-random binary sequence (PRBS) generator, encoder and the driver electronics for IR LED. Test data is generated using the PRBS generator circuit and the encoder output giving $3/16$ pulse is logically ANDed with the generated data. The encoded output is fed to the IR LED driver circuit. The schematic diagram of Transmitter circuit is in Fig. 4.1

4.1.1 PSEUDO-RANDOM BINARY SEQUENCE GENERATOR

A pseudo random binary sequence (PRBS) generator of length 7 was implemented using a four bit Universal shift register (IC 74F194), an XOR gate (IC 7486) and a few NOR gates (IC 7425). This PRBS data used as the test data in all the implementation

This shift register is fully synchronous with all operations taking place in less than 20ns (typically). The operation of the device is determined by two mode select S_0 and S_1 . The functions available with these mode select inputs are right-shift, left-shift, parallel load and hold. The circuit diagram of the PRBS generator is shown in Fig. 4.1. In this circuit the shift register was configured in the right-shift mode. It is important to prevent the all zero state in a PRBS generator as such a state would prevent the generator from outputting PRBS data, instead will be locked to all zero's state. We have incorporated an auto start circuit comprising of three OR gates from a 74S32 IC and a Not gate from 74F04 IC. Under normal conditions (for non zero states) the output of the NOT gate would be a logical '0' which is connected to the S_1 mode input which will give a shift right operation with $S_0 = '1'$. When all zero state is detected the Not gate output will become '1' thereby forcing the shift register to be parallel load '1100' into the shift register, thus taking it out of the all zero state.

4.1.2 ENCODER

Serial data from PRBS generator is fed to COUNT UP input of an 4-bit binary synchronous up/down counter (74F193). The above counter used in the UP mode only in our implementation by connecting the COUNT DOWN-'N-Clock' permanently to '1'. A clock which is 16 times the desired baud rate was fed to the COUNT UP-Clock input of 74F193. The asynchronous reset pin, and the parallel load input were both connected to '1' as these functions were not used. The counter worked as a simple 4-bit UP counter, with 16 states. In order to generate a 3/16 pulse for low input data, a combinational circuit is utilized whose output is high from the 7th clock state to the 10th state and low for all the other states. The 3/16 pulse so generated is ANDed with the complement of the PRBS data so that the 3/16 pulse is present only for logical 0 of the data. The encoded data is then fed to the IR LED driver.

4.1.3 IR LED DRIVER ELECTRONICS

The IR LED driver circuit is indicated in Fig.4.1. It consists of a four input 50-ohm line driver (74S140) which had a maximum I_{OL} (output-Low-level current) of 68mA and maximum I_{OH} (output-High-level current) of 40mA. This IC is made using a high speed Schottky technology and can hence be used to drive 50 ohm loads directly. The availability of this driver IC made it possible to design a high speed driver circuit. We designed the circuit such that the I_{OL} current will flow through the LED when the input to the gate is a logical 1. The maximum I_{OL} current of a single gate was not sufficient to meet the LED current requirements. Hence two such gates were connected in parallel to get double the current. Also, it was possible to exceed the dc I_{OL} limits without damage to the IC since the encoder output was always a pulse. In our implementation we forced I_{OL} values of about

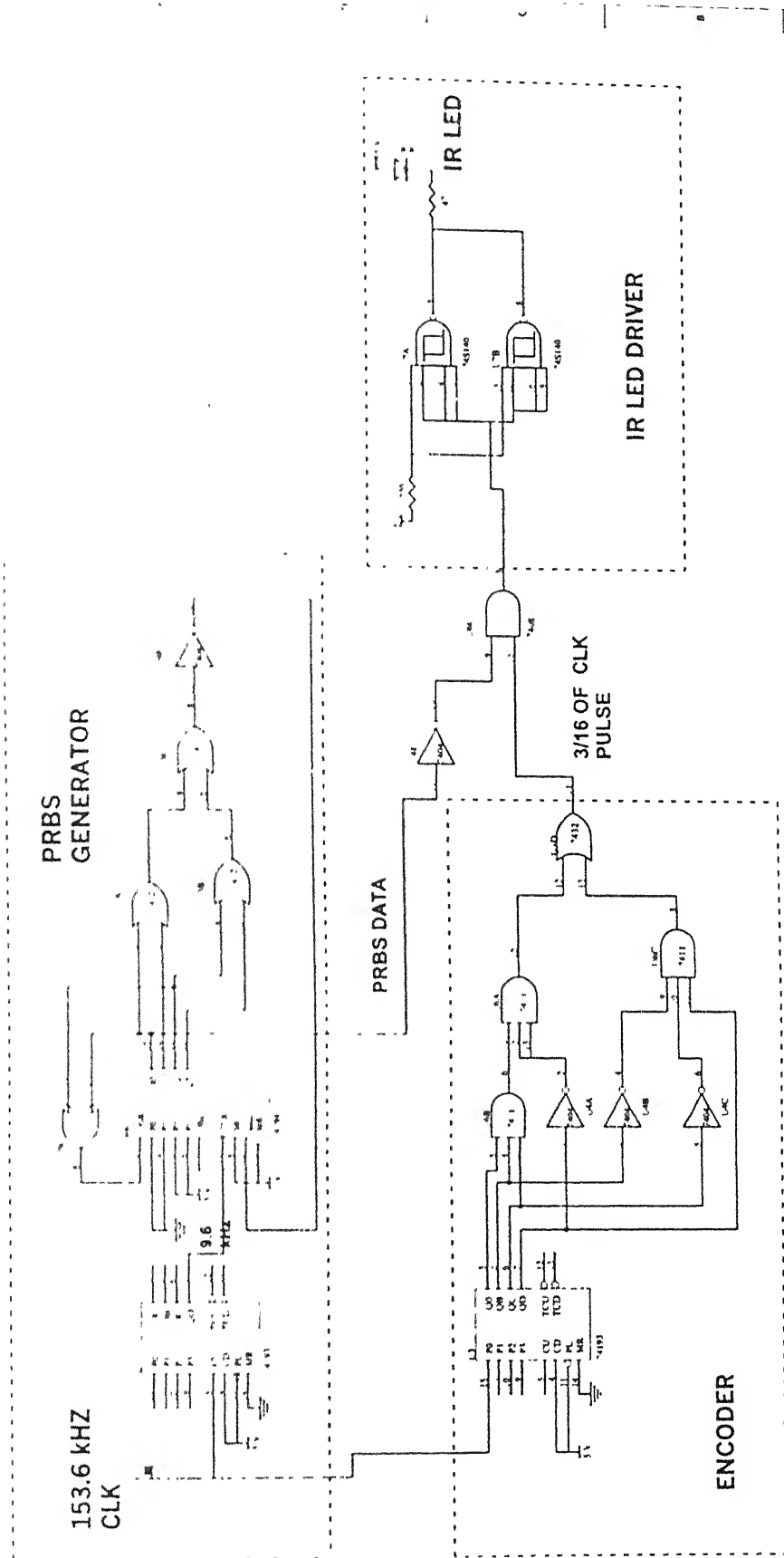


Fig. 4.1 INFRARED LED TRANSMITTER

80 mA per gate to get high peak current and thus high peak optical output from the LED. Assuming VOL (output-voltage-low) value of the gate to be 0volts, using KVL, the current flowing through the LED is given by.

$$I_{LED} = (V_{CC} - V_{LED})/R_{LED} \quad (4.1)$$

where $V_{LED} = 1.7 \text{ V}$, is the forward voltage drop of the IR-LED

For $R_{LED} = 33 \text{ ohms}$, the $I_{LED} = 100/2 = 200\text{mA}$

One of the major problems was to locate a high speed and high radiance IR-LED. Since high radiance IR LEDs were not available, we used IR-LEDs used in Television Remote Controls, which were available cheap. In our study we used only one IR-LED as the source.

4.2 RECEIVER CIRCUIT

The receiver circuit comprises of PIN detector, trans-impedance amplifier, peak detector, summing amplifier, comparator and decoder as shown in Fig. 4.2

4.2.1 PIN DETECTOR AND TRANSIMPEDANCE AMPLIFIER

The detector used in our receiver circuit is RCA C-30808, which is a n-type silicon PIN detector. A reverse bias of 12V was applied and the detector. Important parameters of the C-30808 detector are as follows

Dark current	= 20 nA
Radius of active area	= 1.26 mm
Maximum bias voltage	= 15 V
Reponsivity at 900 nm	= 0.65 A/W
Capacitance	= 6 pF

The detector has smaller active area and radius and was well suited for applications up to data rates of several Mbits/s.

A transimpedance amplifier circuit was realized using TL-081 Operational amplifier. This opamp has a gain-bandwidth product of 5MHz. We used a feed back resistor of 750 Kohms, which gave a good tradeoff between bandwidth of the preamplifier and the signal output.

One of the problems faced in indoor applications is the large variation in the optical powers at the photodetector input. The optical signal after being detected and amplified is finally applied to a comparator for conversion to digital data. Generally, such comparator circuits are given a fixed reference voltage (threshold) for conversion to digital data. Since the received signal amplitude can have large variation, fixed reference voltages will cause signal-strength dependent errors. In order to tackle this problem there should be some kind of adaptive threshold for the comparator circuit. In our study such an adaptive approach was implemented using opamp based peak detectors and summer as explained below

4.2.2 PEAK DETECTOR AND SUMMING AMPLIFIER

The prerequisite for indoor link is that the receiver should have a wide dynamic range. The receiver should respond properly when the transmitter is very far from it and it should not saturate when the transmitter is very close to it. Under such conditions a simple fixed-threshold comparator will give rise to errors. To solve this problem peak detector circuits were designed and implemented to detect both high and low peaks of the received signal. These peak detectors were implemented using TL-081 opamps.

Fig. 4 2 shows a *peak detector* that measures the positive peak values of the square wave input. During the positive half-cycle of v_{in} , the output of the op-amp drives D_1 on, charging capacitor C to the positive peak value V_p of the input voltage D_1 . Thus, when D_1 is forward biased, the op-amp operates as a voltage follower. On the other hand, during the negative half-cycle of v_{in} , diode D_1 is reverse biased, and voltage across C is retained. For proper operation of the circuit, charging time constant (CR_d) and discharging time constant (CR_L) must satisfy the following conditions:

$$CR_d \leq T/10 \quad (4.2)$$

where R_d = resistance of the forward-biased diode, 100Ω , typically

T = time period of the input waveform and

$$CR_L \geq 10T \quad (4.3)$$

where R_L is the load resistor. The resistor R is used to protect the op-amp against the excessive discharge currents, especially when the power supply is switched off. The resistor $R_{OM} = R$ minimizes the offset problems caused by input currents. In addition, diode D_2 conducts during negative half-cycle of v_{in} and hence prevents the op-amp from going into negative saturation. This in turn helps to reduce the recovery time of the op-amp. Negative peaks of input signal v_{in} can be

detected simply by reversing diodes D_1 and D_2 . The outputs from positive and negative peak detectors goes to a summing amplifier in inverting configuration. The output voltage V_o , which is obtained from Kirchoff's current equation written with respect to inverting input node is as follows

$$V_o = -((R_f/R_a)*V_{a1} + (R_f/R_b)*V_{b1}) \quad (4.4)$$

Where $R_a, R_b = 12\text{ K}$ and $R_f = 120\text{ K}$, V_{a1} and V_{b1} are the amplitudes of positive and negative peak detectors from the preceding stage. The output voltage of the summing amplifier is given to an average circuit which is a R-R voltage divider. This averaged voltage is applied to the reference input of the NE529 comparator.

4.2.3 COMPARATOR

The comparator converts signals from an analog to a digital form by comparing the input signal with a threshold voltage, which the R-R voltage divider output provides. NE529 is a high speed comparator which can have input voltages as low as 60 mV at the signal input. The output of the comparator is TTL level signal which is fed to the decoder to obtain the actual transmitted data.

4.2.4 DECODER

The received signal at the output of the comparator are encoded. It is important to note that the transimpedance amplifier used causes inversion to the signal as its output is $-I_{sig} R_f$. Hence the signal output at the comparator will be the complement of the encoded signal at the transmitter. The signal at the comparator output was inverted using a 74F04 NOT gate to restore its correct phase. The decoder consists of a 74F193 UP/DOWN counter, some gates and finally a D-flip-flop. In addition to this a non-inverting buffer was used to adjust propagation delays. The inverted comparator output suitably delayed is applied to the asynchronous RESET input of the 74F193 counter.

Let us assume a data pattern of '0110' at the input to the encoder. Corresponding to this the encoder would have produced a 3/16 pulse corresponding to the first and the last logical 0 in the above data. So at the decoder when the 3/16 pulse appears, the counter will be reset to all zero. The Q3 output is Or-ed with the encoded data, which is acting as a clock pulse to the D-flip-flop. The 74174 d-flip flop (F/F) is a positive going one. Hence at the negative going edge of the 3/16th pulse the clock to the D- F/F will be positive going. Since the data corresponding to this is a logical 0, the D input to the F/F is inverted. Hence whenever the counter RESET input is logical 1,

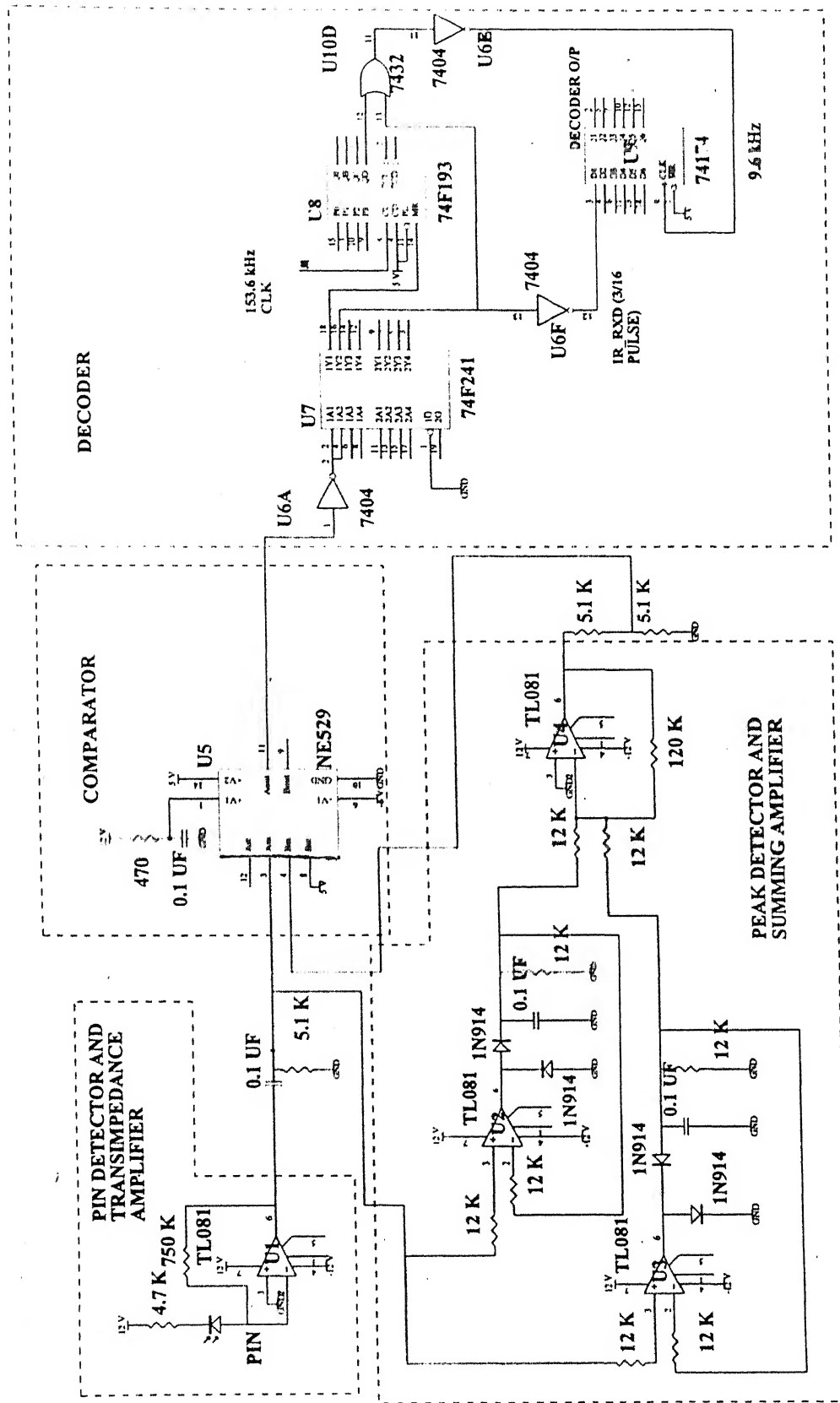


Fig. 4.2 RECEIVER CIRCUIT

the D-input to the F/F will be logical 0. Hence the D-F/F will produce a logical 0 at its Q output. Since the next two data bits considered in our example are logical 1s, there will not be any IR pulses nor are any comparator outputs. Hence the counter RESET input will be at logical 0 and it is free to count up to 16 (i.e. 1111). At the 16th clock pulse, Q3 output of the counter will go from high to low, resulting in a low to high transition at the D-F/F clock input. Since there was no data at the comparator output the signal at the D-input of the F/F will be a logical 1 and hence the Q output of the F/F will give logical 1 output. For the next data bit (which is logical 1 in our example) also the same actions continue and a logical 1 will be decoded. For the last data bit of logical 0, there will be a 3/16th pulse which will cause the counter to be reset and the decoded output will be a logical 0. A detailed timing diagram of the decoder is shown in Fig.4.3.

4.3 PERFORMANCE OF THE SUBSYSTEMS

Characteristics of the sub systems were measured and were compared with the design requirements. One of the important characteristics was that of the optical source. Similarly, the performance of the receiver was measured.

4.3.1 LED SOURCE CHARACTERIZATION

The LED sources used in our system were commercial IR LEDs, used for remote control applications in Television receivers, with light emission centered around 820 nm. The two major source characteristics that are important in wireless IR communication are current intensity (optical power) profile and far-field characteristics. The former would give an idea about the driver current for a given power and is useful in the driver circuit design.

A simple setup for current-intensity measurement is shown in Fig. 4.4 and the measured characteristics in Fig. 4.5. The measured relation between LED current and its optical power is found to be almost linear. It was not possible to measure the LED output at currents higher than 20 mA as the LED optical power was above milliwatts range, which was beyond the capability of the power meter and the large area detector available in the laboratory. Hence the LED power outputs at a current of 100mA could not be determined.

4.3.2 MEASUREMENT OF RECEIVER CHARACTERISTICS

The performance of the Si PIN detector based receiver was measured. The major receiver parameters are sensitivity, maximum data rate capability and dynamic range.

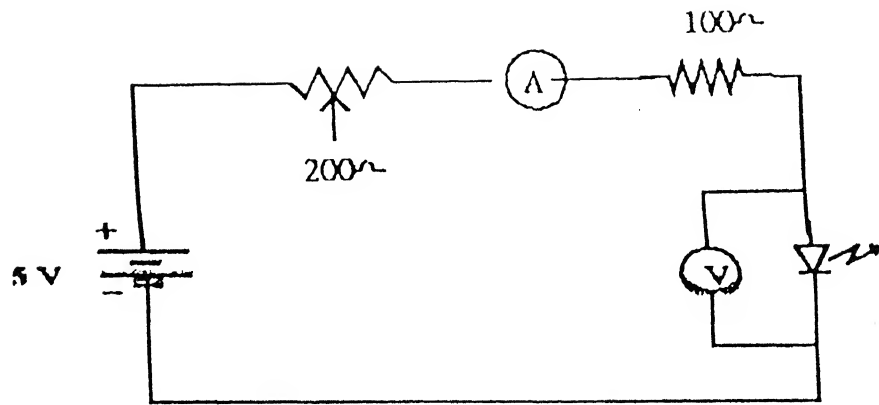


Fig 4.1, Current – Intensity Characteristics Set up

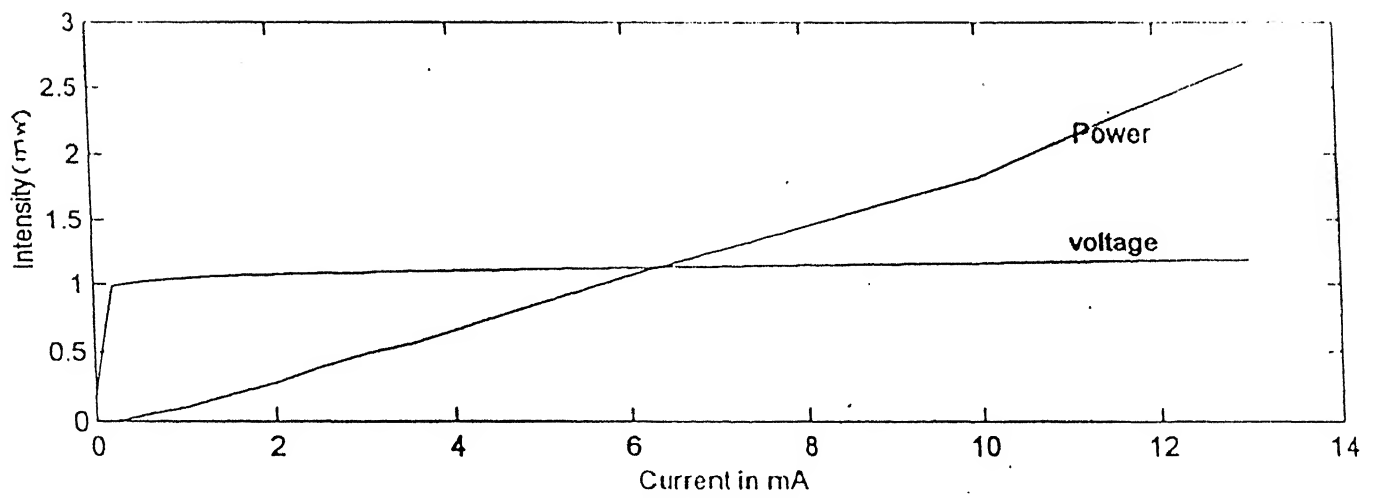


Fig 4.5 Current-Intensity Characteristics results

4.3.2.1 Sensitivity

Receiver sensitivity is defined as the minimum optical power required at the photodetector to obtain a certain Bit error rate or SNR performance. Sensitivity is a strong function of data rate as it deteriorates with increasing data rate. The sensitivity of the PIN detector based transimpedance receiver was found to be -35 dBm (300 nW) at a data rate of 200 Kb/s.

4.3.2.2 Dynamic range

The dynamic range gives the allowed variation in the optical power at the receiver. Our receiver was found to have a dynamic range of 30 dB at 200 Kb/s. This is a fairly large figure and is due to the adaptive threshold scheme used in our receiver.

4.3.2.3 Maximum data rate

The maximum data rate capability of the circuit was about 1.2Mb/s. However the sensitivity and dynamic range were quite inferior at this data rate. So we have to restrict our experiments to 200 kb/s.

4.4 TESTS CARRIED OUT USING THE EXPERIMENTAL LINK

In order to test the performance of our indoor optical link, the transmitter and the receiver circuits designed were tested in two modes. In the first mode the full link was tested with all the blocks, viz., PRBS generator, encoder, LED transmitter, PIN based receiver and decoder. In the second mode, the optical link was tested without using the encoder and decoder.

4.4.1 PERFORMANCE MEASURE OF EXPERIMENTAL LINK WITH ENCODER AND DECODER

The Encoder/Decoder so designed was tested with the PRBS data generator. The advantage of using encoder/decoder was that LED is turned ON only whenever a '0' is transmitted and the duration of the IR pulse was $19.53 \mu\text{s}$ for baud rate of 9.6 kb/s. It was turned 'OFF' the rest of the time. In this manner the power requirement is reduced, since the IR LED needs current only for a short duration whenever a logical 0 is transmitted. Hence it is possible to increase the peak LED power to large values, without causing much increase to the average power.

The performance of the IR link was tested at the recommended data rates of 2.4 kb/s, 9.6 kb/s, 19.2 kb/s, 38.4 kb/s, 57.8 kb/s, and 115.6 kb/s. The PRBS data, and the encoded bit pattern were monitored along with the received data bits, which was further decoded and found to match exactly with the transmitted data. The maximum range attained with this test setup was about 30 cm. For this case (maximum source – detector distance = 30cm) the LED current was increased to 440 mA by using a R_{LED} value of 7.5 ohms. In each of the above cases the 16X clocks were generated at the transmitter and the receiver using Function Generators. It is worth noting that the actual transmitted data rate for the baud rate of 115.6 kb/s was 1.84 Mb/s. Thus we were able to test the LED transmitter and receiver circuits up to 1.84 Mb/s.

4.4.2 PERFORMANCE MEASURE OF EXPERIMENTAL LINK WITHOUT ENCODER, DECODER FOR FILE TRANSFER APPLICATION FROM PC TO PC

One of the critical elements in this experimental link is the 16X clock both at the transmitter and the receiver required for encoding and decoding. For applications involving encoder and decoder it was assumed by the architects of the IrDA standards that a standard UART chip will be available at both ends without extra cost. However, when we want to use this experimental link as a means of interfacing two PCs, such assumptions are not valid. In present day PCs, the Baudout pin of 82510 UART chip on the Serial I/O card is not available, since they are all made ASICs and the pin is not available for external usage purposes. We found that only very old PCs (286 systems) had the facility of providing 16X clocks.

Hence, we had to eliminate the encoder and decoder in interfacing PCs. The RS232 ports of the PCs were used for this purpose. In order to obtain RS232 compatible levels (+3 to +12V for a logical 0 and –3 to –12V for logical 1) level translators had to be used along with the present transmitter and receiver. Details of the PC-PC interfacing with the optical link are given below.

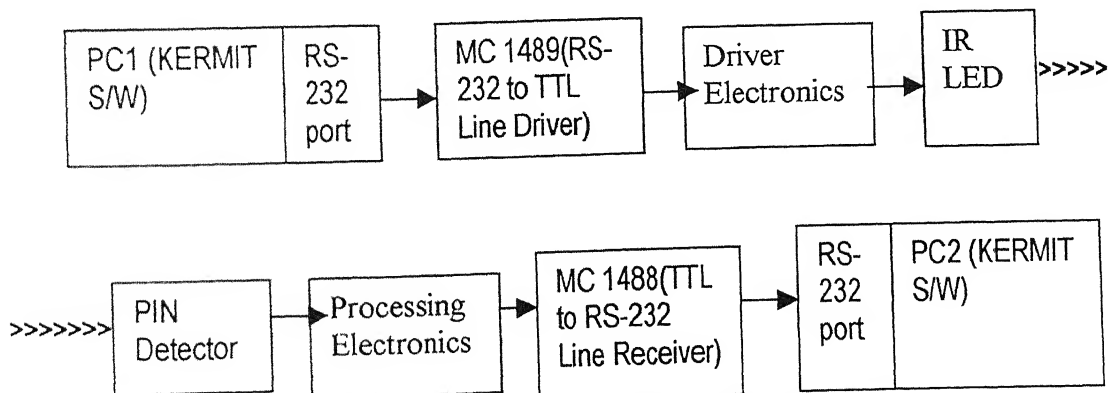


Fig. 4.6 Block Schematic Diagram of PC-PC File Transfer Configuration

File transfers between the Transmit-PC and the Receive-PC were done through KERMIT software. At the Transmit-PC, the TXD pin of the RS232 was taken to MC 1489 (RS-232 to TTL driver) and then given to the IR transmitter. The IR receiver at the Receive-PC end received the signals which were then translated to RS232 levels using MC1488 (TTL to RS232 driver). The level translated signal was then applied to the RXD pin of the Receive-PC. We used KERMIT software (DOS based) for testing the hardware for file transfer application. In KERMIT one can select the desired baud rate (which should be same in both the transmitting and receiving PCs) the serial port address, and the 'SEND filename' and 'RECEIVE file name' commands.

4.5 TEST METHODOLOGY

Three tests to evaluate the RS-232 port, the alignment of the Experimental link, and finally file transfer application are carried out as follows

- LOOP BACK METHOD
- LOCAL ECHO MODE
- FILE TRANSFER

4.5.1 LOOP BACK METHOD

This is for hardware functional check of the RS-232 port (COM1 port). The RXD and TXD pins are shorted together. And the KERMIT program is executed. If the data transmitted matches with the received data it signifies that the RS-232 port is functioning properly. If any error is encountered, it means that the port is faulty. The same procedure must be repeated on the COM2 port of the PC.

4.5.2 LOCAL ECHO MODE

Here the PC2 is assigned as a 'DUMB TERMINAL' (receive mode) and the data is transmitted through RS-232 port of the PC1 and both PCs must be set to the same baud rate with local echo on. Whenever characters are being typed from PC1, they will be received by PC2 and displayed on the monitor. If they match with the transmitted data, it means that both the serial ports of both PCs are working and the set up is ready for file transfer. This also implies that the transmitter and receiver is aligned perfectly. If there is discrepancy in the data received then manually align the transmitter and receiver and repeat the procedure.

4.5.3 FILE TRANSFER

The transmitter hardware is interfaced to PC1 and the receiver hardware is interfaced to the PC2. In PC2, after initial setting of required baud rate, and selection of port, Kermit command 'RECEIVE' is executed. In PC1, one has to set the same baud rate as set in PC2, and Kermit command 'SEND filename' is executed. On the monitor of both the PCs, the information of % of Kbytes of data transmitted and the data transfer status, whether it is success or failure, will be displayed.

For baud rates of 9.6Kb/s, 19.2Kb/s, 38.4Kb/s and 57.6 kb/s, files were transferred from PC1 to PC2 successfully using the experimental link. The maximum separation distance achieved between the transmitter and receiver was 10 cm.

START

CONNECT TXD(PIN 2) &
GND(PIN 7) OF THE RS-232
PORT OF PC1 TO THE
TRANSMITTER HARDWARE

RESTART THE PC1 IN DOS MODE &
EXECUTE KERMIT

VERIFY THE FUNCTIONALITY OF RS-232
PORT BY LOOP BACK METHOD
'CONNECT'

SET PORT 2(COM 2)
SET SPEED 9600(bp/s)

SET LOCAL ECHO ON
TYPE 'CONNECT'

AFTER PC2 IS SET TO 'CONNECT MODE'
TYPE CHARACTERS AND ENSURE THAT THE
SAME IS DISPLAYED ON PC2

A

START

CONNECT THE OUTPUT OF THE
RECEIVER H/W FROM MC-1489
TO RXD(PIN 3) & GND(PIN 7) OF
THE RS-232 PORT OF PC2

RESTART THE PC2 IN DOS MODE
&EXECUTE KERMIT

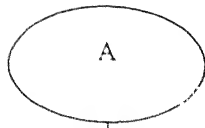
VERIFY THE FUNCTIONALITY OF RS-232
PORT BY LOOP BACK METHOD
'CONNECT'

SET PORT 1(COM 1)
SET SPEED 9600(bp/s)

SET LOCAL ECHO ON
'TYPE CONNECT'

LOOK FOR MATCH OF THE TRANSMITTED DATA BY
PC1 ON THE MONITOR OF PC2

B



IF THERE IS DISCREPANCY, THEN ADJUST THE POSTIONS OF TRANSMITTER AND RECEIVER HARDWARE MANUALLY AND REPEAT THE PROCEDURE

ONCE THE HARDWARE IS PERFECTLY ALIGNED, GO FOR FILE TRANSFER

ALWAYS START WITH SET SPEED 9600

SEND 'FILE NAME'

ENSURE PC2 IS IN RECEIVE MODE, TYPE SEND 'FILE NAME' COMMAND

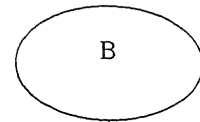
THE NO. OF BYTES BEING TRANSFERRED, % OF TRANSFER, AND ANY ERRORS ENCOUNTERED, AND THE SOURCE 'FILE NAME' WILL BE DISPLAYED

NO

TASK OVER

YES

EXIT KERMIT



WAIT TILL THE HARDWARE IS PERFECTLY ALIGNED, GO FOR FILE TRANSFER

ALWAYS START WITH SET SPEED 9600

'RECEIVE'

SET SPEED FROM 9.6-57.6 kb/s

THE NO. OF BYTES BEING TRANSFERRED, % OF TRANSFER, AND ANY ERRORS ENCOUNTERED, AND THE DESTINATION 'FILE NAME' WILL BE DISPLAYED

YES

TASK OVER

NO

EXIT KERMIT

CHAPTER 5

CONCLUSIONS, SUGGESTIONS FOR FURTHER WORK

The major aim of the work was to design and implement an IrDA compatible experimental indoor point-to-point link for indoor applications. An extensive review on indoor optical wireless systems was also carried out.

Data transfers at 2.4 kb/s, 9.6Kb/s, 19.2Kb/s, 38.4Kb/s, 57.6 kb/s and 115.6 kb/s were carried out using IrDA compatible IR links making use of recommended encoder and decoder. PC to PC data transfers at 9.6Kb/s, 19.2Kb/s, 38.4Kb/s and 57.6 kb/s were done with the help of KERMIT software.

Based on our study it can be concluded that IrDA compatible are ideally suited for indoor data transfer between instruments and also PC to PC. In our study easily available sources and detectors and general purpose components were used to implement the experimental link. However, in order to achieve the recommended distance of 1m meter between the transmitter and the receiver it is necessary to use highly radiant LEDs. The sensitivity of the receiver must also be improved to achieve maximum separation between source and detector.

In our study it was found that IrDA compatible data transfer between PCs is not possible without sufficient hardware and protocol support. The need to generate synchronized 16X clock at both the end was found to be a hurdle in using IrDa recommended encoder and decoder.

SUGGESTIONS FOR FURTHER WORK

It is suggested that higher baud rates, viz. MIR and FIR specifications as per IrPHY of IrDA standards should be tried out using communication controller chips which has the features of higher baud rates, CRC implementation. In order to increase the range array of LEDs should be used in place of a single LED. The driver electronics for the transmitter has to be redesigned for larger current ratings and the detector electronics too has to be redesigned to meet higher baud rates and low noise requirements.

REFERENCES

- 1 R.H Saul, "Recent advances in the performance and reliability of InGaAsP LED's for light wave communication systems," *IEEE trans. On Electron Devices*, Vol. ED-30, No. 4, April 1983, pp. 285-295
- 2 J.M.Kahn, John R Barry," Wireless Infrared Communications," *Proc. Of the IEEE*, Vol. 85, No. 2, Feb. 1997,pp 265-298.
- 3 D M.Fye,"Low-current 1.3- μ m Edge-Emitting LED for single-Mode Fiber Subscriber Loop Applications." *Journal of light wave technology*, Vol. LT-4, No. 10, Oct. 1986, pp. 1546-1551
4. J.R.Barry et al, " High-speed-Non-Directive optical communication for wireless Network," *IEEE Network magazine*, Vol. 67, No. 6, Nov. 1991, pp. 44-54.
- 5 M.R.Pakravan, E.Simova, M. Kavehrad, " *Holographic Diffusers for indoor Infrared Communication Systems*," IEEE, 1996, pp. 1608-1612.
6. P. Eardley et al, " Holograms for Optical wireless LAN's," *IEE Proc. Opto-elect.,Special issue on free space optical communications*, Dec. 1995.
7. D.Wisely et al., "4 km terrestrial line of sight optical free space link operating at 155 Mb/s," *Proc. Free Space Laser commun. Tech. VI*, SPIE, Vol. 2123, 1994.
8. F.R.Gfeller and U.Bapst, "Wireless in-house data communication via diffuse infrared radiation," *Proc. IEEE*, Vol 67, No. 11, Nov. 1979.
9. T.S.Chu and M.J. Gans, " High speed infrared local wireless communications", *IEEE communications magazine*, Vol. 25, No. 8. Pp. 4-10, Aug. 1987.
10. Lessard et al, " Wireless communication in the Automated Factory Environment", *IEEE Network magazine*, Vol. 2, No. 3, pp. 64-69, May 1988.
11. Stephen R Forrest, " Optical detectors: Three contenders," *IEEE Spectrum*, pp. 76-84, May 1986.
12. S.D.Personick, "Receiver design for digital Fiber optic communication systems, I and II," *Bell system Technical Journal*, Vol. 52, No. 6, pp. 843-886, July-Aug. 1973.
13. Earl Herger, " Optical Detector Selection: A delicate balancing Act!," *Electronic Design*, pp. 11-24, March 3, 1997.
14. A.C.Boucoulalas, " Indoor ambient light noise and its effect on wireless optical links," *IEE Proc. Optoelectronics*, Vol. 143, No. 6, pp. 334-338,Dec. 1996.

15. A Moriera, R. Valadas, and A. Duarte, "Performance of Infrared Transmission systems under ambient light interference," *IEE proc. Optoelectronics*, Vol. 143, No.6, pp. 339-346, Dec 1996.
16. A.M.Street, "Indoor optical wireless systems- a review," *Optics & Quantum electronics*, pp 349-378, July 1997
17. D.P.Johnson et al. "Free Space Infrared Local area network (FIRLAN)," *Optical Engineering* Vol 32, No 9, pp 2114-2117, Sep 1993.
18. Kaveh Pahlavan, "Wireless Communications for office information networks," *IEEE communication magazine*, Vol 23, No. 6, pp. 19-27, June 1985
19. Z Ghassemlooy and A.R. Hayes, "Digital pulse interval modulation for optical communications," *IEEE communication magazine*, pp. 95-99, Dec 1998.
20. Ian Miller, Martin Beale et al, "The IrDA standards for high speed Infrared communications," *The Hewlett-Packard journal*, pp. 1-20, 1998.
21. Lee Goldberg, "Infrared Data Transmission: The missing link?," *Electronics Design*, pp. 47-64, April 17, 1995
22. Brian Ingham and Richard Helms, "Infrared's Role in Wireless Communication Expands with IrDA," *Electronics Design*, pp. 52-58
23. David J.T. Heatly, David R. Wisely et al, "Optical Wireless: The Story So Far," *IEEE Commun. Mag.* pp 70-82, Dec. 1998.
24. Jose' J.G. Fernandes, "Wireless LANs: Physical Properties of Infra-Red Systems Vs. MmW Systems," *IEEE Communication Magazine*, pp. 68-73, Aug. 1994.
25. Nicholas Baran, "Wireless Networking," *Byte*, pp. 291-294, April 1992.
26. Tran Van Muoi, "Receiver Design for High-speed Optical Fiber Systems," *Journal Of Lightwave Technology*, pp. 243-267, June 1994.
27. David J.T. Heatly, David R. Wisely et al, "Optical Wireless. The Story So Far," *IEEE Commun Mag* pp. 70-82, Dec. 1998.
28. K Pahlavan, "Wireless Data Communications," *Proc. Of the IEEE*, pp. 1398-1428, Sep. 1994
29. Jose' J.G. Fernandes, "Wireless LANs: Physical Properties of Infra-Red Systems Vs. MmW Systems," *IEEE Communication Magazine*, pp. 68-73, Aug. 1994.
30. Nicholas Baran, "Wireless Networking," *Byte*, pp. 291-294, April 1992.

INTERNET WEBSITES :

- 1 www.irda.org
- 2 www.usa.canon.com
3. www.cablefree.co.uk
- 4 www.4uinfo.com
- 5 www.jolt.co.il

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